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INSIGHTS INTO FOOD CONSUMPTION, VITAMIN D STATUS, AND ASSOCIATED FACTORS AMONG ADULT IMMIGRANT POPULATIONS IN FINLAND: FINDINGS FROM POPULATION-BASED AND INTERVENTION STUDIES

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Insights into food consumption, vitamin D status, and associated factors among adult immigrant populations in Finland: findings from population-based and intervention studies

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“It always seems impossible until it’s done.” – Nelson Mandela

To my beloved mother (the late *Alice Morenike Olayemi*) who became ill while I was about to submit this thesis for pre-examination and passed on on 31 May 2019.

AND

To “My Favourite” – my husband (*Gabriel Omotosho Adebayo*) who inspired and supported me throughout the PhD pursuit.

ABSTRACT

Diet is an indicator of health and chronic disease. Food consumption patterns of a particular population may define their nutrient intake, including vitamin D, revealing their health profiles. The food consumption patterns among immigrants often differ from those of the host population, and health inequalities exist between these two groups. Vitamin D insufficiency (S-25(OH)D <50 nmol/L), which has been associated with bone disorders, such as osteoporosis, and risk for cancers and other chronic diseases, is a public health problem among populations at northern latitudes, especially during winter because of low ultraviolet B irradiation and reduced skin synthesis of vitamin D. Nevertheless, the risk of vitamin D insufficiency is higher among non-Western immigrants, particularly dark-skinned ones, living in these regions. In the Nordic countries, vitamin D status in the majority of the host populations seems to be better than that of immigrants.

This study seeks insights into immigrants' nutrition with the aims of examining food consumption and vitamin D status among immigrants of Russian, Somali, and Kurdish background. The study also aimed to investigate whether ethnic differences exist in the response of serum 25-hydroxyvitamin D (S-25(OH)D) to vitamin D_3 supplementation between Somali and Finnish women. The thesis was based on three datasets: i) a cross-sectional population-based Migrant Health and Wellbeing Study (Maamu Study), ii) the nationally representative Finnish Health 2011 Survey (Health 2011), and iii) the randomized controlled trial Marwo-D intervention study.

Study I (n=1372) comprised immigrant participants aged 18-64 years from the Maamu Study. Healthy food consumption frequencies were evaluated among 527 Russian, 337 Somali, and 508 Kurdish men and women, through dietary questions in interviews. Data on socio-demographic factors were obtained from a sampling frame and through interviews. Potential socio-demographic determinants of healthy food consumption were assessed by logistic regression. Immigrants of Russian background more frequently consumed healthy foods, especially rye bread, vegetables, fruits, and berries, than Kurds and Somalis. Female sex, older age, and higher education were positively associated with healthy food consumption. Low consumption of fresh vegetables, fruits and berries was observed among Somali immigrants.

In Study II, the S-25(OH)D concentrations of 1310 immigrants (446 Russians, 364 Somalis, and 500 Kurds) aged 18-64 years from the Maamu Study and a Finnish reference group aged 30-64 years from the Health 2011 Survey (n=798) were standardized according to the Vitamin D Standardization Program (VDSP) by liquid chromatography-tandem mass spectrometry. Data on socio-demographic, lifestyle, and dietary habits were obtained from a sampling frame and through structured interviews or through a self-administered

health questionnaire. Vitamin D status (S-25(OH)D) of the immigrant groups was analysed relative to the Finnish reference group through linear regression. The consumption of dietary vitamin D sources and the potential socio-demographic, lifestyle, and dietary determinants of low vitamin D status i.e. deficiency (S-25(OH)D <30 nmol/L) and insufficiency (<50 nmol/L), were evaluated with logistic regression analyses. The prevalence of vitamin D deficiency and insufficiency was higher among the immigrants, especially Somalis and Kurds, than among the Finns ($p<0.001$). Consumption of vitamin D-rich foods differed between the immigrant groups; vitamin D-fortified fat spread was commonly used by a higher proportion of Somalis than Russians and Kurds; fish consumption was less frequent among Kurds than among Russians and Somalis; and higher proportions of Russians and Kurds consumed vitamin D-fortified dairy daily than Somalis ($p<0.001$ for all). The main determinants of low S-25(OH)D concentration were daily smoking, alcohol consumption, obesity, and winter blood sampling ($p\leq0.04$). Older age, physical activity, consumption of fish, vitamin D-fortified fat spread, and dairy products, and use of vitamin D supplements were associated with reduced odds of low S-25(OH)D concentration ($p\leq0.04$).

In Study III, 191 subjects were screened and 147 women (Somali n=72, Finns n=75) aged 21-64 years were randomized to receive placebo or 10 or 20 µg vitamin D_3/d in a 5-month trial during winter in the Helsinki area (60°N). S-25(OH)D concentrations were assessed by liquid chromatography-tandem mass spectrometry. Background and dietary data were collected through a detailed questionnaire and a validated semi-quantitative interview-administered food frequency questionnaire. Response of S-25(OH)D to vitamin D_3 supplementation was assessed with repeated-measures analysis of covariance. Vitamin D status (S-25(OH)D) and vitamin D intake from diet and supplements were analysed. High prevalence of vitamin D insufficiency was observed among Somali women at screening. Interestingly, total vitamin D intake was higher among Somalis, but their baseline mean S-25(OH)D concentrations were lower than among Finns ($p<0.001$ and $p=0.001$, respectively). Moderate vitamin D_3 supplementation at doses of 10 µg and 20 µg effectively increased mean S-25(OH)D in both Somali and Finnish women, without ethnic differences in the response to supplementation ($p>0.05$).

In conclusion, food consumption patterns among immigrants with Russian, Somali, and Kurdish background were not similar. Healthy foods, particularly rye bread, vegetables, fruits, and berries, were consumed more by Russian immigrants than by participants with Kurdish and Somali background. Frequent consumption of fresh vegetables and fruits and berries was uncommon among Somalis. Higher consumption frequency of the healthy foods was associated with some socio-demographic factors, namely female sex, older age, and higher education. Likewise, differences existed in the consumption of vitamin D-rich foods between the immigrant groups. Use of vitamin D-fortified fat spread was more frequent among Somalis than among Russians and Kurds; fish consumption frequency was lower among Kurds than among Russians and Somalis; and vitamin D-fortified dairy was more frequently consumed daily by Russians and Kurds than by Somalis. The extent of the risk of low vitamin D status also differed between immigrant groups; higher prevalence of vitamin D deficiency and insufficiency was observed among Somalis and Kurds than among Russians. Hence, the immigrant groups cannot be considered a homogeneous group. In addition, non-fair-skinned immigrants are at higher risk of deficiency/insufficiency than their host populations. This thesis demonstrated that moderate vitamin D_3 supplementation was effective in increasing S-25(OH)D in both Somali and Finnish women, and supports previous findings that ethnicity has no effect on the response of S-25(OH)D to vitamin D supplementation. Promotion of healthy food consumption patterns, including fruits, vegetables, whole-grains, and vitamin D-rich foods, is essential among immigrant groups to improve overall health.

TIIVISTELMÄ, Finnish summary

Ravinto määrittää terveyttä ja kroonisten sairauksien riskiä. Väestöryhmien ruokatottumukset ilmentävät ravintoaineiden, kuten D-vitamiinin, saantia sekä terveydentilaa. Ulkomaalaistaustaisten ruokatottumukset usein eroavat koko väestön tottumuksista, ja ryhmien välillä esiintyy terveyseroja. Riittämätön D-vitamiinitila (seerumin 25-hydroksi-D-vitamiinipitoisuus [25(OH)D] <50 nmol) on yhteydessä luuston häiriötiloihin, kuten osteoporoosiin, sekä syövän ja kroonisten sairauksien riskiin. Se on kansanterveydellinen ongelma pohjoisilla leveysasteilla erityisesti talviaikaan, sillä auringon ultravioletti-B-säteilyä ei saada tarpeeksi, jolloin D-vitamiinisynteesiä iholla ei tapahdu. Riittämättömän D-vitamiinitilan riski on suurempi ei-länsimaalaistaustaisilla, etenkin tummaihoisilla, jotka asuvat näillä leveysasteilla. Pohjoismaissa suurimmalla osalla väestöstä D-vitamiinitila on parempi kuin ulkomaalaistaustaisilla.

Tässä väitöskirjassa selvitettiin ruokatottumuksia ja D-vitamiinitilaa venäläis-, somali- ja kurditaustaisilla väestöryhmillä. Lisäksi tavoitteena oli selvittää eroja vasteessa D-vitamiinisuplementaatioon somali- ja suomalaisnaisilla. Väitöskirja koostui kolmesta eri aineistosta: i) väestöpohjainen poikkileikkausasetelmana toteutettu Maahanmuuttajien terveys- ja hyvinvointitutkimus (Maamu), ii) koko väestöä edustava Terveys 2011 –tutkimus ja iii) satunnaistettu, kontrolloitu MarwoD-interventiotutkimus.

Osatyö I:n aineisto (n=1372) koostui 18-64-vuotiaista ulkomaalaistaustaisista tutkittavista (Maamu-tutkimus). Terveellisten ruokien käyttötiheyttä selvitettiin 527 venäläis-, 337 somali- ja 508 kurditaustaiselta mieheltä ja naiselta haastattelulla. Tieto sosiodemografisista muuttujista kerättiin tutkittavien otantakehikosta ja haastattelemalla. Terveellisten ruokien käyttöä selittäviä sosiodemografisia tekijöitä tutkittiin logistisilla regressiomalleilla. Venäläistaustaiset käyttivät useammin terveellisiä ruokia, erityisesti ruisleipää, vihanneksia, hedelmiä ja marjoja, kuin kurdi- ja somalitaustaiset. Naissukupuoli, vanhempi ikä ja korkeampi koulutustaso olivat positiivisessa yhteydessä terveellisten ruokien käyttöön. Tuoreiden kasvisten, hedelmien ja marjojen käyttö oli vähäistä somalitaustaisilla.

Osatyössä II määritettiin 25(OH)D-pitoisuudet Maamu-tutkimuksen 1310 ulkomaalaistaustaiselta 18-64-vuotiaalta (446 venäläis-, 364 somali- ja 500 kurditaustaista) ja vertailuryhmänä toimi Terveys 2011- tutkimuksen koko Suomen 30-64-vuotiasta väestöä edustava otos samoilta paikkakunnilta (n=798). Näytteet standardoitiin D-vitamiinin standardointiohjelman (Vitamin D Standardization Program) mukaisesti nestekromatografia-tandem-massaspektrometriamenetelmällä. Tieto sosiodemografisista tekijöistä, elintavoista ja ruoankäytöstä kerättiin tutkittavien otantakehikosta, strukturoiduilla haastatteluilla ja itsetäytettävällä terveyskyselyllä. D-vitamiinitilan

(25(OH)D) eroja ryhmien välillä tutkittiin lineaarisilla regressiomalleilla. Ravinnon D-vitamiinin lähteiden käyttöä ja D-vitamiinin puutoksen (25(OH)D <30 nmol/l) ja riittämättömän pitoisuuden (25(OH)D <50 nmol/l) sosiodemografisia sekä elintapoihin ja ruoankäyttöön liittyviä selittäjiä analysoitiin logistisilla regressiomalleilla. D-vitamiinin puutos ja riittämätön D-vitamiinitila olivat yleisempiä ulkomaalaistaustaisilla, etenkin somali- ja kurditaustaisilla, kuin koko väestössä ($p<0.001$). D-vitamiinia sisältävien elintarvikkeiden käyttö erosi ryhmien välillä: D-vitamiinilla täydennettyjen rasvalevitteiden käyttö oli yleisempää somali- kuin venäläis- ja kurditaustaisilla; kalan käyttö oli vähäisempää kurdi- kuin venäläis- ja somalitaustaisilla; suurempi osuus venäläis- ja kurditaustaisista käytti päivittäin D-vitamiinilla täydennettyjä maitovalmisteita somalitaustaisiin verrattuina ($p<0.001$). Matalaa 25(OH)D-pitoisuutta selittivät vahvimmin päivittäinen tupakointi, alkoholin käyttö, lihavuus ja verinäytteenotto talviaikaan ($p\leq0.04$). Vanhempi ikä, fyysinen aktiivisuus, kalan, D-vitaminoitujen rasvalevitteiden ja maitovalmisteiden sekä D-vitamiinilisien käyttö suojasivat matalan 25(OH)D-pitoisuuden riskiltä.

Osatyössä III yhteensä 191 naista Helsingin alueelta (60°N) seulottiin tutkimuksen sisäänottovaiheessa ja heistä 147 (72 somali- ja 75 suomalaistaustaista), iältään 21-64-vuotiaita, satunnaistettiin saamaan joko lumevalmistetta tai 10 tai 20 mikrogramman suuruista päivittäistä D_3-vitamiiniannosta viiden kuukauden ajan. 25(OH)D-pitoisuudet määritettiin nestekromatografia-tandem-massaspektrometriamenetelmällä. Tutkittavien taustatiedot kerättiin kyselylomakkeella ja ruoankäyttötiedot validoidulla semikvantitatiivisella ruoankäytön frekvenssikyselylomakkeella. 25(OH)D-pitoisuuden vastetta D_3-suplementaatioon tutkittiin toistomittausten varianssianalyysillä. 25(OH)D-pitoisuudet ja D-vitamiinin saanti ravinnosta ja ravintolisistä analysoitiin. Tutkimuksen sisäänottovaiheessa suurella osalla somalitaustaisista D-vitamiinitila oli riittämätön. Tutkimuksen lähtötilanteessa D-vitamiinin kokonaissaanti oli somalitaustaisilla suurempi kuin suomalaistaustaisilla, mutta silti 25(OH)D-pitoisuudet olivat heillä keskimäärin matalampia kuin suomalaistaustaisilla ($p<0.001$, $p=0.001$). Kohtuullinen D-vitamiinisuplementaatio 10 ja 20 mikrogramman päivittäisannoksilla nosti tehokkaasti 25(OH)D-pitoisuuksia sekä somali- että suomalaistaustaisilla, mutta vasteessa ei havaittu ryhmien välisiä eroja ($p>0.05$).

Loppupäätelminä voidaan todeta, että ruokatottumukset venäläis-, somali- ja kurditaustaisilla eivät olleet samanlaisia. Venäläistaustaiset käyttivät terveellisiä ruokia, etenkin ruisleipää, kasviksia, hedelmiä ja marjoja, enemmän kuin kurdi- tai somalitaustaiset. Tuoreiden kasvisten, hedelmien ja marjojen käyttö ei ollut yleistä somalitaustaisilla tutkittavilla. Terveellisten ruokien tiheämpi käyttö oli yhteydessä sosiodemografisiin tekijöihin, erityisesti naissukupuoleen, vanhempaan ikään ja korkeampaan koulutustasoon. Samoin D-vitamiinia sisältävien elintarvikkeiden käytössä oli eroja ryhmien välillä. D-vitamiinilla täydennettyjen rasvalevitteiden käyttö oli yleisintä somalitaustaisilla; kalan käyttö oli vähäisintä kurditaustaisilla ja suurempi osa venäläis- ja kurdi- kuin somalitaustaisista käytti D-vitamiinilla täydennettyjä maitovalmisteita päivittäin. Matalan 25(OH)D-pitoisuuden riski vaihteli ryhmien välillä: puutos ja riittämätön D-vitamiinitila olivat yleisempiä somali- ja kurdi- kuin venäläistaustaisilla. Tutkimuksen perusteella voidaan sanoa, että ulkomaalaistaustaisia ei voida ravitsemuksellisten riskien osalta tarkastella yhtenäisenä ryhmänä. Ei-vaaleaihoisilla ulkomaalaistaustaisilla on suurempi matalan 25(OH)D-pitoisuuden riski kuin koko väestöllä. Tämä väitöskirja vahvisti aiempia tutkimustuloksia siitä, että kohtuullinen D_3-vitamiinisuplementaatio on tehokas nostamaan 25(OH)D-pitoisuuksia ja ulkomaalaistaustalla ei ole vaikutusta D-vitamiinisuplementaation aiheuttamaan 25(OH)D-pitoisuuden vasteeseen. Terveellisten ruokatottumusten, mm. kasvisten, hedelmien, täysjyväviljan ja D-vitamiinia sisältävien elintarvikkeiden käytön, edistäminen ulkomaalaistaustaisilla on tärkeä osa heidän ja koko väestön terveyden edistämistä.

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications, which are referred to in the text by their Roman numerals (I-III):

I Adebayo FA, Itkonen ST, Koponen P, Prättälä R, Härkänen T, Lamberg-Allardt C, Erkkola M. Consumption of healthy foods and associated socio-demographic factors among Russian, Somali and Kurdish immigrants in Finland. Scand J Public Health 2017;45:277-287.

II Adebayo FA, Itkonen ST, Lilja E, Jääskeläinen T, Lundqvist A, Laatikainen T Koponen P, Cashman KD, Erkkola M, Lamberg-Allardt C. Prevalence and determinants of vitamin D deficiency and insufficiency among three immigrant groups in Finland - evidence from a population-based study using standardized 25-hydroxyvitamin D data. Submitted.

III Adebayo FA, Itkonen ST, Öhman T, Skaffari E, Saarnio E, Erkkola M, Cashman KD, Lamberg-Allardt C. Vitamin D intake, serum 25-hydroxyvitamin D status and the response to moderate vitamin D3 supplementation: a randomised control trial in East African and Finnish women. Br J Nutr 2018;119:431-441.

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Contribution of the authors to Studies I-III

I: FAA, CL-A and ME were involved in the conception, design and implementation of the study. FAA drafted the manuscript and analysed the data with the guidance of ME. PK and RP assisted with data collection in the Maamu study. TH provided advice on statistical analyses. Evaluation of the results, comments and critical revisions of the manuscript were done by STI and the other co-authors. All co-authors read, contributed to and approved the final manuscript.

II: FAA, STI, ME and CL-A conceived the study. FAA, STI, EL, TJ, AL, TL, PK, ME and CL-A contributed to the study design. TL and PK were involved in the planning and data collection of the Maamu Study. TJ, AL and PK were involved in the Health 2011 Survey's data collection. KDC was responsible for the standardization of the S-25(OH)D data. FAA performed the statistical analysis with the guidance of EL. Evaluation of the results was done by STI, EL, TJ, AL, TL, PK, KDC, ME and CL-A. FAA interpreted the results and wrote the paper. Critical reviews of the manuscript were done by all co-authors. All authors revised and approved the final manuscript.

III: CL-A and KDC are grant holders. FAA, STI, TÖ, ES, EMS, ME and CL-A were involved in the design of the study. FAA, TÖ, ES and EMS collected the data. KDC was responsible for the S-25(OH)D analyses at the University College Cork, Ireland. FAA drafted the manuscript and performed the statistical analysis with the guidance of STI. Evaluation of the results and comments on and critical reviews of the manuscript were done by STI, ME and CL-A. All co-authors reviewed and approved the final draft of the manuscript.

ABBREVIATIONS

$1,25(OH)_2D$	1,25-dihydroxyvitamin D, calcitriol
25(OH)D	25-hydroxyvitamin D, calcidiol
ANCOVA	analysis of covariance
ANOVA	analysis of variance
AR	average requirement
AUDIT	Alcohol Use Disorders Identification Test
BMD	bone mineral density
BMI	body mass index
Ca	calcium
CHD	coronary heart disease
CI	confidence interval
CLIA	chemiluminescence immunoassays
CVD	cardiovascular disease
CYP2R1	25-hydroxylase, cytochrome P450 2R1
CYP24A1	24-hydroxylase, cytochrome P450 24A1
CYP27B1	25(OH)D-1α-hydroxylase, cytochrome P450 27B1
DEQAS	Vitamin D External Quality Assessment Scheme
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
FFQ	food frequency questionnaire
FNR	Finnish Nutrition Recommendations
Health 2011	Health 2011 Survey
HPLC	high-performance liquid chromatography
IOM	Institute of Medicine
LC-MS/MS	liquid chromatography-tandem mass spectrometry
LI	lower intake level
Maamu Study	Migrant Health and Wellbeing Study
MetS	Metabolic syndrome

NA	not applicable
NNR	Nordic Nutrition Recommendations
ODIN	Food-based solutions for optimal vitamin D nutrition and health through the life cycle
OR	odds ratio
Pi	phosphate
PTH	parathyroid hormone
RCT	randomized controlled trial
RI	recommended intake
RIA	radioimmunoassay
S-	serum
SD	standard deviation
T2D	type 2 diabetes mellitus
THL	Finnish Institute for Health and Welfare
UL	upper intake level
UVB	ultraviolet B
VDR	vitamin D receptor
VDSP	Vitamin D Standardization Program
Vitamin D	calciferol
Vitamin D_2	ergocalciferol
Vitamin D_3	cholecalciferol

1 INTRODUCTION

The number of immigrant populations in Europe is increasing. In Finland, persons with foreign background currently constitute 7% of the population (Statistics Finland 2019). Differences in health profiles exist between the immigrant populations and the host populations; the risk of non-communicable diseases is higher in minority groups (Stronks *et al.* 2013). Dietary patterns or behaviours of a group of people may define their nutrient intake and may be influenced by different factors; acculturation, among others, may be an important element among immigrant populations (Holmboe-Ottesen & Wandel 2012). Hence, the association between ethnic health inequalities and diet could be understood by studying the food consumption patterns and their determining factors such as socio-demographic factors (Dekker *et al.* 2015).

Adoption and adherence to a healthy diet are essential in preventing adverse health outcomes and enhancing long-term health. A health-promoting diet with a high consumption of vegetables, berries, and fruits, a daily consumption of whole-grain bread and other whole cereal products, and a consumption of fish 2-3 times a week has been emphasized in the Finnish Nutrition Recommendations (FNR) (National Nutrition Council 2014). Moreover, fish consumption according to the recommendations and frequent consumption of vitamin D-fortified fat spreads and fluid dairy products ensure adequate vitamin D intake (Lamberg-Allardt 2006). Adequate consumption of these vitamin D-rich foods and/or use of vitamin D supplements is important in countries at northern latitudes, such as Finland, where the best source of vitamin D – synthesized in the skin – is inadequate during winter months due to limited sunlight exposure.

Vitamin D plays a vital role in skeletal development in children and maintenance of bone health in adults. Sufficient status (serum 25-hydroxyvitamin D (S-25(OH)D) >50 nmol/L) is beneficial in the prevention of osteoporosis and fractures and decreased risk of falls (Ross *et al.* 2011, Nordic Council of Ministers 2014). Nevertheless, vitamin D insufficiency (S-25(OH)D <50 nmol/L) is a public health problem among populations living at northern latitudes, with a higher prevalence of deficiency (S-25(OH)D <30 nmol/L) among immigrants living in the region (Ross *et al.* 2011, Van der Meer et al. 2011, Spiro & Buttriss 2014, Lips and de Jongh 2018). Hence, the risk of bone diseases and non-skeletal conditions, including cancers, cardiovascular disease (CVD), and type 2 diabetes mellitus (T2D), which have been associated with vitamin D insufficiency (S-25(OH)D <50 nmol/L) (Rejnmark *et al.* 2017, Bouillon *et al.* 2019), becomes a great concern, especially among immigrant groups who are most vulnerable regarding vitamin D deficiency.

In the Nordic countries, vitamin D status in the majority of the host populations seems to be more satisfactory than among immigrants (Andersson *et al.* 2013, Wändell 2013). In addition, infrequent consumption of fatty fish or use of vitamin D supplements has been observed among immigrants of non-Western origin living in the Nordic countries (Wändell 2013, Granlund *et al.* 2016), thus the reported high prevalence of vitamin D deficiency among the groups may be partly explained by nutritional factors. In Finland, higher prevalence of vitamin D deficiency and insufficiency has also been previously observed among immigrant women (Somali and Bangladesh) than among Finnish women (Islam *et al.* 2012). On the contrary, sufficient vitamin D status (S-25(OH)D >50 nmol/L) was reported among the majority (77-91%) of the general Finnish population (Jääskeläinen *et al.* 2017, Raulio *et al.* 2017). In the recent national dietary survey (FinDiet 2017), fat spreads and dairy products, which are fortified in Finland, and fish were reported as the major dietary vitamin D sources, accounting for 83% of daily vitamin D intake among Finnish men and 79% among Finnish women (Valsta *et al.* 2018).

Having dark skin poses an increased risk of low vitamin D status; such is evident based on the high prevalence of vitamin D deficiency often observed among immigrants of African and Asian background residing in the northern countries (Andersen *et al.* 2008b, Islam *et al.* 2012, Andersson *et al.* 2013). Despite the inequalities in vitamin D status between dark-skinned and fair-skinned populations, the same vitamin D recommendations, which are based on studies among Caucasian populations, are made for the two populations in the Nordic countries and in the United States (Ross *et al.* 2011, Nordic Council of Ministers 2014). Nevertheless, differences in vitamin D requirement and metabolism between the different population groups may exist (Cashman 2014). The impact of ethnicity and the need for dose-response studies in relation to vitamin D status were emphasized in the Institute of Medicine (IOM) Dietary Reference Intakes report (Ross *et al.* 2011). In addition, several factors, such as wearing concealing clothes, higher body mass index (BMI), physical inactivity, smoking, and low education status, have been reported as determinants of low vitamin D status (Holick 2006, Jääskeläinen *et al.* 2013, Granlund *et al.* 2016, Yao *et al.* 2017).

The number of immigrants, especially the dark-skinned population, is increasing in Finland. Nevertheless, there is a lack of information about dietary habits and vitamin D status among immigrants. In relation to the health situation of immigrants, it is important to study their dietary patterns, including the most important vitamin D sources, adherence to nutrition recommendations, and associated factors. In addition, knowledge of vitamin D status among immigrants living in northern countries, who are particularly in danger of vitamin D deficiency, is crucial. In order to gain novel insights into nutrition information for immigrants in Finland, the present study aimed to evaluate consumption of healthy foods and the associated socio-demographic factors (Study I), dietary sources of vitamin

D, and determinants of low vitamin D status among immigrants with Russian, Somali, and Kurdish background (Study II). The vitamin D status of the immigrant groups was also examined relative to that of the general Finnish population (Study II). Furthermore, the response of S-25(OH)D to vitamin D_3 supplementation and vitamin D intake and status were compared between Somali and Finnish women (Study III).

2 REVIEW OF THE LITERATURE

2.1 Food consumption and dietary guidelines

2.1.1 Nordic and Finnish dietary guidelines and recommendations

Diet is an essential modifiable determinant of health or chronic disease (Willett *et al.* 2006, Bhupathiraju & Tucker 2011). Studies have established the relationship between unhealthy diets and various non-communicable diseases such as CVD, T2D, and some cancers (GBD 2017 Diet Collaborators 2019). On the other hand, adoption of a healthy diet plays a significant role in preventing adverse health outcomes and enhancing long-term health (Kant 2004, Willett *et al.* 2006). Health status of any population is better understood through food consumption patterns rather than single nutrients or foods (Tapsell *et al.* 2016). Many countries around the world have established their own dietary recommendations or guidelines, which are often based on dietary patterns, among other factors, in order to promote general health and prevent chronic diseases (FAO 2015).

The FNR (National Nutrition Council 2014) are based on the Nordic Nutrition Recommendations (NNR), a current scientific and evidence-based joint policy document towards best possible health for the Nordic population at large (Nordic Council of Ministers 2014). The recommendations are partly food-based dietary guidelines for the general population emphasizing healthy dietary pattern of frequent consumption of vegetables, berries, and fruits, whole-grain cereals, and fish (2-3 times a week). In addition, they promote use of vegetable oil-based fat spreads and vegetable oils in cooking, consumption of low-fat dairy products or alternatives, consumption of low-fat and low-salt meat products, and limited intake of red and processed meat, sugar, salt, and alcohol (National Nutrition Council 2014, Nordic Council of Ministers 2014). The focus on the whole diet in both recommendations is based on the role of dietary patterns and food groups in the prevention of diet-related chronic diseases (Nordic Council of Ministers 2014).

Adherence to these recommendations is expected to reduce the risk of most chronic diseases and enhance healthy populations. The evident health impact of specific food groups from different studies is well documented in the NNR. For instance, a consistent conclusion is that high consumption of vegetable, fruit, and berries is associated with reduced risk of CVD (Aune *et al.* 2017, Miller *et al.* 2017). Studies have reported convincing protective associations between whole-grain consumption and total risk of CVD, coronary heart disease (CHD), and stroke (Ye *et al.* 2012, Aune *et al.* 2016), risk of weight gain or obesity (Fogelholm *et al.* 2012, Ye *et al.* 2012), and T2D (Ye *et al.* 2012, Aune *et al.* 2013, Aune *et al.* 2016). The convincing health impact of fish consumption comprised a reduction in the risk of cardiovascular mortality, including that of ischaemic stroke (Zhao *et al.* 2016, Hengeveld *et al.* 2018, Jayedi *et al.* 2018). Fatty fish consumption was also associated with reduced blood pressure (Ramel *et al.* 2010) and better insulin sensitivity (Ramel *et al.* 2008). Reduced risk of T2D and CHD was associated with lower intake of processed and red meat (Männistö *et al.* 2010, Fretts *et al.* 2012, Micha *et al.* 2012).

In evaluating adherence to NNR, findings among people with metabolic syndrome (MetS) or MetS risk factors in four Nordic countries (including Finland) revealed low adherence to nutrition recommendations, which may result in T2D and CVD (Jonsdottir *et al.* 2013). Similar to the FNR, the NNR is the key reference point for nutritional recommendations in other Nordic countries. According to Renzella *et al.* (2018), studies that investigated health effects of different Nordic national dietary guidelines, which are based on NNR, found associations between increased adherence and reduced risk of non-communicable diseases and risk factors. Such health conditions included stroke (Hansen *et al.* 2018a), myocardial infarction (Hansen *et al.* 2018b), atherosclerosis (Øverby *et al*. 2007), non-high-density lipoprotein cholesterol concentration (Uusitupa *et al.* 2013), and cardiovascular events (Hlebowicz *et al.* 2013). A few studies have also examined adherence to FNR; low adherence to dietary recommendations was observed among individuals with type 1 diabetes (Ahola *et al.* 2012). According to Kanerva *et al.* (2013), adherence to FNR is helpful in healthy weight maintenance and particularly associated with healthy waist circumference and body fat percentage. Lower risks for gestational diabetes were reported among pregnant Finnish women with a higher adherence to FNR and NNR (Meinilä *et al.* 2017).

Besides emphasis on dietary patterns, NNR stressed the importance of optimal nutrient intake in order to reduce diet-associated diseases (Nordic Council of Ministers 2014). Hence, NNR also establishes recommended intakes (RI) for some single nutrients because of their impact on public health (Nordic Council of Ministers 2014). Among other nutrients, vitamin D intake is crucial in the Nordic countries due to latitudes (55º N-72° N) at which sun-induced vitamin D production in the skin is limited, especially during wintertime (Nordic Council of Ministers 2014). Thus, vitamin D deficiency and its associated health outcomes can be prevented through the consumption of diets rich in vitamin D. It is worth noting that the RI, the estimated intake likely to meet the nutrient requirements of nearly 97.5% of the population (Nordic Council of Ministers 2014), for vitamin D in NNR has doubled within the period 1996-2012, increasing from 5 µg to 10 µg (Nordic Council of Ministers 2014, Fogelholm 2018). The significant change in the vitamin D recommendation is associated with its special importance to the Nordic population (Fogelholm 2018). Thus, the current vitamin D recommendations in both NNR and FNR are based on recent scientific evidence for higher requirements and concern about population health (Lamberg-Allardt 2013, Fogelholm 2018).

2.1.2 Vitamin D dietary guidelines and recommendations in Finland

The vitamin D recommendations for the general population in Finland are in line with NNR and they include provide for daily RI, average requirement (AR), lower intake level (LI), and upper intake level (UL) (National Nutrition Council 2014, Nordic Council of Ministers 2014). The recommendations are based on evidence for an association between vitamin D intake/status and health outcomes such as fractures, falls, CVD, and total mortality (Nordic Council of Ministers 2014). Such evidence includes the consensus that vitamin D intake of 10 µg/d is required to maintain S-25(OH)D concentrations around 50 nmol/L among the majority of the population during the winter season at the latitudes of the Nordic region (Nordic Council of Ministers 2014). In 2012, the RI (i.e. estimated intake to achieve S-25(OH)D concentration of at least 50 nmol/L in almost all of the population) was further increased to 10 µg/d for children and adults (aged 2-74 years, including pregnant and lactating women) (National Nutrition Council 2014, Nordic Council of Ministers 2014). However, an intake of 10 µg/d is also recommended for children under 2 years in Finland (National Nutrition Council 2014). In consideration of the additional limited sun-induced vitamin D synthesis and evidence of a protective effect of vitamin D intake against fractures, falls, and mortality, a higher intake of 20 µg/d was set for the elderly (>75 years) who may have little or no sun exposure also during the summer (National Nutrition Council 2014, Nordic Council of Ministers 2014).

The NNR states that AR, the estimated intake sufficient to meet the requirement for 50% of a defined group of people, is 7.5 µg/d (Nordic Council of Ministers 2014). The LI remained 2.5 µg/d; long-term intakes below the LI are associated with an increased risk of developing deficiency symptoms (Nordic Council of Ministers 2014). The UL for adolescents and adults (high intake with increased potential adverse effect such as hypercalcaemia and kidney failure) is 100 µg/d, and for children aged 1-11 years 50 µg/d (Nordic Council of Ministers 2014, National Nutrition Council 2018). In line with the European Food Safety Authority (EFSA), the new ULs for infants aged 0-6 months and 6-12 months are 25 µg/d and 35 µg/d, respectively (EFSA 2018, National Nutrition Council 2018).

Due to habitual consumption of fatty fish and vitamin D-fortified foods (such as dairy products and margarine) among the Finnish population (Lamberg-Allardt *et al.* 2013), it is possible to achieve the daily recommended vitamin D intake from food (Raulio *et al.* 2017). Hence, adherence to the current recommended daily consumption of about three glasses of vitamin D-fortified fat-free/low-fat milk products or alternatives, fish consumption 2-3 times a week, and frequent use of vitamin D-fortified fat spread is important in attaining the daily required vitamin D intake (National Nutrition Council 2014). Nevertheless, use of vitamin D supplements is recommended in order to meet the need of individuals of special age groups (such as all children below 18 years and the elderly) and persons who consume less vitamin D-rich foods (Lamberg-Allardt *et al.* 2013, National Nutrition Council 2014). These guidelines are set mainly in relation to bone health such as prevention of rickets in children and osteomalacia, risk of falls, and fractures in adults (National Nutrition Council 2014). The current recommended guidelines for vitamin D intake and supplementation in Finland according to age are summarized in Table 1.

Table 1. *Current recommendations for daily vitamin D intake and tolerable upper intake level.*

Age group	Recommended vitamin D intake (μg/d)[*1]	Recommendation for supplementation (μg/d)[1]
2 weeks – 12 months	10	2 – 10[**] (year-round)
1 – 2 years	10	10 (year-round)
2 – 17 years	10	7.5 (year-round)
18 – 74 years	10	†
Pregnant and lactating women	10	10 (year-round)
≥ 75 years	20	20[††] (year-round)
	Tolerable upper intake level (μg/d)	
< 6 months	25[2]	
6 – 12 months	35[2]	
1 – 11 years	50[1]	
≥ 11 years	100[1]	

Total intake from foods and supplements

[**]Based on whether the infant is exclusively breast-fed or receives infant formula or a follow-on formula: 10 μg/d for exclusively breast-fed and a child receiving <500 ml/d infant formula/follow-on formula and 6 μg/d and 2 μg/d for a child receiving 500-800ml and ≥800ml infant formula/follow-on formula, respectively.

[†]10 μg/d supplement use if necessary (i.e. when vitamin D-fortified milk products, fat spread, and/or fish are not consumed during wintertime; period of limited sun-induced dermal production of vitamin D).

[††]Lower supplement dose of 10 μg/d may be sufficient if vitamin D-fortified milk products, fat spread, and/or fish are regularly consumed.

[1]Recommendation by NNR and FNR

[2]Recommendation by EFSA and FNR

2.1.3 Socio-demographic differences in food consumption

Socio-demographic factors, such as age, sex, education level, marital status, and employment status, are important determinants differentiating dietary patterns among people (Barkoukis 2007, Gregório *et al.* 2017, Leone *et al.* 2017), which may thus define their state of health. Several studies have examined the association between socio-demographic factors and consumption of specific food groups or dietary patterns (Table 2). Regarding adherence to dietary recommendations, increasing age, better education status, professional occupation, and being on a diet were identified as factors associated with higher compliance (Estaquio *et al.* 2009, Alkerwi *et al.* 2012, de Abreu *et al.* 2013). Poor adherence was associated with male sex, current smoking, manual workers, and subjects with little knowledge of the importance of balanced meals (Estaquio *et al.* 2009, Alkerwi *et al.* 2012, de Abreu *et al.* 2013). High body mass index (BMI) has also been found to be associated with low adherence to nutrition recommendations (Estaquio *et al.* 2009, de Abreu *et al.* 2013). However, better compliance was reported among obese individuals than among those with normal weight in a study conducted in Luxembourg (Alkerwi *et al.* 2012). Concerning country of birth, better adherence to dietary recommendations was observed among non-native subjects (Portuguese) than among natives of Luxembourg (Alkerwi *et al.* 2012), and among non-Swiss-born participants than among those born in Switzerland (de Abreu *et al.* 2013).

Generally, better socio-demographic profiles are associated with healthy dietary patterns. For example, higher education and higher income have been linked to healthy dietary patterns (Kant 2004, Arruda *et al.* 2014). Healthy dietary patterns comprising fruits, vegetables, whole-grains, low-fat dairy, nuts, or fish are commonly associated with older age, female sex, and higher educational level (Arruda *et al.* 2014, Knudsen *et al.* 2014, Gregório *et al.* 2017, Marques-Vidal *et al.* 2018).

Unhealthy dietary patterns, including high intake of red meat, fatty foods, or convenience foods, are more associated with male sex, lower level of education, and younger age (Arruda *et al.* 2014, Knudsen *et al.* 2014, Gregório *et al.* 2017, Marques-Vidal *et al.* 2018). It was suggested that younger people are more likely to adopt convenient foods such as hamburgers, pizzas, or ketchup (Sánchez-Villegas *et al.* 2003). In addition to higher education and being older, being married or cohabiting was associated with greater adherence to a Mediterranean dietary pattern in Italy (Leone *et al.* 2017). According to Sánchez-Villegas *et al.* (2003), married individuals are more likely to uphold the traditional Mediterranean dietary habits compared with the less healthy food choices of persons who are single, widowed, or divorced.

Sex differences in consumption of healthy foods have been described in terms of awareness and knowledge of nutrition, which tend to be higher among women because they seek nutrition counselling and make use of the advice received more frequently than men (Kiefer *et al.* 2005). Hence, this reveals a higher degree of health consciousness among women than men (Knudsen *et al.* 2014) and better knowledge about health-diet relationship implications among women (Thiele & Weiss, 2003). In addition, the quest to control and maintain body weight (Kiefer *et al.* 2005) and good physical condition (Newby & Tucker 2004, Kiefer *et al.* 2005, Arganini *et al.* 2012), which influences eating habits, is more common among women. Although, men are aware of healthy consumption guidelines, their approach towards nutrition tends to be simple and pleasure-oriented (Kiefer *et al.* 2005). According to Arganini *et al.* (2012), this attitude among men is possibly due to their perception of healthy eating as monotonous and unsatisfying. Moreover, in contrast to women, men will rather engage in exercise than adjust their eating habits as an option for weight control (Kiefer *et al.* 2005).

Job insecurity or unemployment is also more associated with meat consumption (Gregório *et al.* 2017). Explanations for high consumption of vegetables and fruits and compliance with the recommendations on meat among highly educated people can be traced to better access and understanding of nutrition information (de Abreu *et al.* 2013, Leone *et al.* 2017, Thiele *et al.* 2017) and possibly higher income to purchase healthy foods (Drewnowski 2010, Thiele *et al.* 2017).

In multi-ethnic populations, dietary patterns can also be described according to racial/ethnic background, mostly in relation to socio-economic status, cultural dietary preferences, and level of integration (Dekker *et al.* 2015). Usually, high adherence to healthy dietary patterns is expected to be associated with better socio-demographic status regardless of ethnicity (ethnic minority groups or the host populations). However, the situation may be different among ethnic minorities or immigrants, especially due to cultural diet preferences (Dekker 2015), which may be unhealthy. Hence, the dietary patterns among immigrants, including those with better socio-demographic status, may be described as a mixed dietary pattern (Wandel *et al.* 2008), which could be less optimal (i.e. between healthy and unhealthy). Immigrants with lower socio-demographic status are likely to spend more on traditional foods (Sharma & Cruickshank 2011) and consume less of the healthy food options in their host countries, especially when such foods (i.e. vegetable, fruits, and nuts) are less associated with their cultural identity (Dekker 2015).

Table 2. *Population-based studies examining associations between socio-demographic factors and food consumption or dietary patterns.*

Authors	Country, n	Age	Female sex	Education	Being married or cohabiting	Employment	Urban
Sánchez-Villegas *et al.* 2003	Spain, n=3847	"Western dietary ↓ pattern"		"Western dietary ↑ pattern"	"Western ↓ dietary pattern"		
Prättälä *et al.* 2007	Finland, Estonia, Latvia and Lithuania, n=25 094		Meat ↓ Fruits ↑ Vegetables ↑	Fruits ↑ Vegetables ↑			Fruits ↑ Vegetables ↑
Figueiredo *et al.* 2008	Brazil, n=2122	Fruits ↑ Vegetables ↑	Fruits ↑ Vegetables ↑	Fruits ↑ Vegetables ↑			
Paalanen *et al.* 2011	Russia and Finland, n=7037		Fruits ↑ Vegetables ↑	Fruits ↑ Vegetables ↑		Vegetables ↑	
Esteghamati *et al.* 2012	Iran, n=3702	Fruits ↓ Vegetables ↓	Fruits ↑ Vegetables ↑				Fruits ↔ Vegetables ↔
de Abreu *et al.* 2013	Switzerland, n=4371	Compliance with recommendations; Fruit ↑ Meat ↑	Compliance with recommendations; Fruit ↑ Vegetable ↑ Meat ↑	Compliance with recommendations; Meat and fish ↑ Fruits ↓ Vegetables ↓ Dairy products ↓			

Arruda *et al.* 2014	Brazil, n=2034		Healthy dietary ↑ pattern	Healthy dietary ↑ pattern			
Irz *et al.* 2014	Finland, Sweden, UK, Italy, n=17 330		Diet quality ↑ Fruits ↑ Vegetables ↑	Diet quality ↑ Fruits ↑ Vegetables ↑ Saturated fat ↓	Diet quality ↑		
Knudsen *et al.* 2014	Denmark, n=3354	“Health-conscious ↑ pattern”	“Health-conscious ↑ pattern”	“Health-conscious ↑ pattern”			
Gregório *et al.* 2017	Portugal, n=7591	“Meat dietary ↓ pattern”	“Meat dietary ↓ pattern”	Meat dietary ↓ pattern”		Meat dietary ↓ pattern”	
Leone *et al.* 2017	Italy, n=8584	Mediterranean ↑ Dietary Pattern		Mediterranean ↑ Dietary Pattern	Mediterranean ↑ Dietary Pattern		
Marques-Vidal *et al.* 2018	Switzerland, n=4372		“Fruits & ↑ Vegetables patterns”	“Fruits & ↑ Vegetables” patterns			Fruits ↔ Vegetables ↔

↑ Positive associations; ↓ inverse association; ↔ no significant association

2.1.4 Immigration and dietary patterns

Immigration is defined as a process by which non-nationals move into a country for the purpose of settlement (International Organization for Migration 2011). There is no universal definition for the term immigrant. However, an immigrant can consequently be referred to as a person who moved from his or her country of origin, to another country for permanent residence. Hence, immigrants in Finland are individuals who have moved to Finland with the intention of residing in the country for over twelve months or have lived in Finland for more than three months without interruption (Statistics Finland 2019).

Immigration is usually accompanied by adaptation to the new environments and cultures of the host countries (Satia 2009). This process includes "dietary acculturation", whereby immigrants gradually adopt the dietary patterns of their new countries (Satia-Abouta *et al.* 2002). Factors affecting adaptation to new food culture among immigrants vary. These may include level of acculturation into the mainstream culture of the host country (Neuhouser *et al.* 2004), extent of contact with people of the host culture (Nicolaou *et al.* 2006, Wandel *et al.* 2008) and good command of the host language (Wandel *et al.* 2008). In addition, residence duration, age at time of migration, and generation status are important acculturation indices that may influence changes in an immigrant's dietary patterns (Sturkenboom *et al.* 2016).

Dietary acculturation has been described as a highly complex process in which the trend of dietary changes in relation to the level of acculturation is inconsistent and multidimensional based on personal, cultural, and environmental factors (Satia-Abouta *et al.* 2002, Satia 2009). Hence, dietary acculturation does not necessarily result in either a deterioration of dietary quality or a convergence with the host population's dietary patterns (Nicolaou *et al.* 2006). For example, Satia-Abouta *et al.* (2002) reported that higher levels of acculturation were positively associated with fruit and vegetable intake, while inverse associations were described by others (Neuhouser *et al.* 2004, Ayala *et al.* 2008, Arandia *et al.* 2012).

Owing to immigration, improvement in dietary habits was observed among South Asian immigrants (from Bangladesh, India, Nepal, Pakistan, or Sri Lanka) in Canada (Lesser *et al.* 2014). Such dietary improvement included increased consumption of fruits and vegetables and decreased intake of high-fat/fried foods (Lesser *et al.* 2014). Notwithstanding the positive changes, consumption of convenience foods, soft drinks, and desserts/candy increased significantly (Lesser *et al.* 2014). A similar overall positive change in dietary practices was found among South Asians (Sri Lankans and Pakistanis) in Norway, especially in fruit and vegetable consumption and fat intake (among the higher educated immigrants) (Wandel *et al.* 2008). However, length of residence was associated with higher red meat consumption in both studies (Wandel *et al.* 2008, Lesser *et al.* 2014).

Preservation of traditional dietary habits may be considered as either healthy or unhealthy depending on the composition of such dietary pattern. For instance, a better diet quality was observed among the North African immigrants (from Tunisia) compared with the French because they maintained their Mediterranean dietary patterns of high consumption of vegetables, fruits, and nuts/beans and low intake of sugar, dairy products, and meat, while living in France (Méjean *et al.* 2007). On the contrary, despite low adherence to a 'red meat, snacks, and sweets' pattern (as a result of preferences for the traditional 'noodle/rice dishes and white meat' pattern) among the Surinamese residents compared with their Dutch peers in Netherlands, the Surinamese had lower scores on 'vegetables, fruit, and nuts' dietary patterns (Sturkenboom *et al.* 2016). In relation to preservation of cultural dietary habits, the Hispanic immigrants from Mexico often consume more fruits and vegetables than the non-Hispanic white residents in Washington, United States, but the findings also revealed likelihood of alteration as the level of acculturation increased (Neuhouser *et al.* 2004). Such alteration was observed with lower consumption of fruits and vegetables among the highly acculturated Hispanics compared with the less acculturated Hispanics (Neuhouser *et al.* 2004).

The food consumption patterns among immigrants, which often differ from that of the host population, also describe their health profiles. Compared with the majority population, the disease risk profile is usually detrimental to the minority groups (Stronks *et al.* 2013). Generally, adoption of the Western diet (characterized by high meat, fat, and snack intake) has been associated with increased risk of obesity, T2D, and CVD among immigrants (Holmboe-Ottesen & Wandel 2012, Lesser *et al.* 2014, Alhazmi *et al.* 2014). Higher prevalence of these health conditions has been found among some ethnic minority groups, compared with their European host population (Jenum *et al.* 2005, Holmboe-Ottesen & Wandel 2012). In contrast, the Tunisian immigrants in France, based on conservation of their traditional Mediterranean dietary patterns, had lower prevalence of overweight than the French, lower prevalence of T2D and CVD than non-immigrant Tunisians, and lower prevalence of hypertension and hypercholesterolemia than both the French and non-immigrant Tunisians (Méjean *et al.* 2007).

Development of nutrition and health promotion programmes for immigrants with a specific focus on their diets has been suggested (Nicolaou *et al.* 2006). Based on the presence of healthy elements in both immigrants' traditional food patterns and that of the Western countries, it is important that immigrants are advised to retain the healthful aspects of their cultural dietary practices while simultaneously adopting the healthful dietary habits of their host countries (Satia-Abouta *et al.* 2002, Nicolaou *et al.* 2006). Moreover, the aspects of the diet that are unhealthy or less optimal should receive special attention (Nicolaou *et al.* 2006). Hence, such nutrition health promotion programmes will facilitate narrowing of the existing health inequalities between immigrants and the native populations.

2.2 Vitamin D

2.2.1 Types and sources of vitamin D

Vitamin D (calciferol) is a fat-soluble nutrient, known as the "sunshine" vitamin, and also is regarded as a hormone due to the ability of its active form 1,25$(OH)_2$D (calcitriol) to function as part of the endocrine system (Ross *et al.* 2011). Vitamin D is a unique nutrient because it can be derived from diets and also be synthesized in the human skin on exposure to sunlight or ultraviolet B (UVB) light of wavelengths 290-315 nm (Lamberg-Allardt *et al.* 2013). The major types of vitamin D are vitamin D_2 (ergocalciferol) and vitamin D_3 (cholecalciferol) (Laird *et al.* 2010). Vitamin D_2 is produced through irradiation of a sterol, ergosterol, which is present in plants and fungi (e.g. some wild mushrooms) (Bikle 2014). Vitamin D_3 is naturally obtained from dietary sources (such as fatty fish, cod liver oil and smaller amounts in egg yolk) (Holick 2007b). In human skin, vitamin D_3 is produced through the action of UVB light on a precursor sterol, 7-dehydrocholesterol (Laird *et al.* 2010). The major differences between the two forms of vitamin D is with D_2 having a double bond between C22 and C23 and a methyl group at C24 in the side chain (Ross *et al.* 2011, Bikle 2014) (Figure 1). Both vitamin D_2 and vitamin D_3 are synthesized commercially and used in food fortification and in dietary supplements (Holick 2007a, Ross *et al.* 2011).

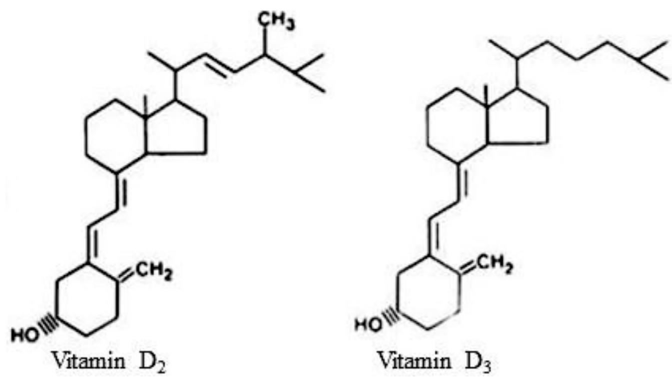

Figure 1. *Structure of vitamin D_2 and D_3.*

The main source of vitamin D for most people is endogenous dermal synthesis (Grant & Boucher 2011). Besides the few foods naturally containing vitamin D, other dietary sources are vitamin D-fortified foods such as milk and dairy products, margarine, breakfast cereals, and orange juice (Holick 2007a). The dietary sources of vitamin D in different countries (e.g. United States, Canada, and European countries) vary due to dietary habits and fortification policies of each country (Spiro & Buttriss 2014). In Finland, fluid milk products, fat spreads, and some plant-based drinks (dairy product alternatives) are fortified with vitamin D based on nutrition policy recommendations (National Nutrition Council 2010). Vitamin D content of some dietary sources is presented in Table 3. In addition, dietary supplements are important sources of vitamin D, especially in countries at northern latitudes, due to limited sunlight exposure during the winter period. Use of dietary vitamin D supplements is essential for individuals who do not frequently consume vitamin D-rich foods or spend time outdoors for sun exposure during summer season (Lamberg-Allardt *et al.* 2013, National Nutrition Council 2014) and for vulnerable individuals such as infants and the inactive elderly (Lamberg-Allardt 2006, Lamberg-Allardt *et al.* 2013).

Table 3. *Vitamin D content of selected dietary sources.*

Sources	Vitamin D content, µg/100g[1]	Sources	Vitamin D content, µg/100g[1]
Fish, raw		**Mushrooms, raw**	
Eel	25.6	Funnel Chanterelle	15.4
White fish	17.9	Chanterelle	5.8
Baltic herring, fillet	15.6	Porcini	2.6
Vendace	9.4	**Egg yolk, raw**	6.5
Salmon, fillet	8.0	**Egg, raw**	2.2
Rainbow trout, fillet	7.8	**Liver, raw (pork)**	1.1
Pike-perch	6.9	**Milk, fortified**	1.0
Tuna	7.2	**Margarine, fortified**	20.0
Cod	7.0	**Plant-based drinks**	
Sardines	5.2	Oat drink, fortified	0.75
		Soya drink, fortified	0.75

[1]Sources: National Food Composition database Fineli®, Finnish Institute for Health and Welfare

2.2.2 Vitamin D synthesis and metabolism

When the skin is exposed to sunlight, the production of vitamin D begins with photochemical transformation of 7-dehydrocholesterol (provitamin D_3) to previtamin D_3 (Tsiaras & Weinstock 2011). The 7-dehydrocholesterol in the dermis and epidermis absorbs solar UVB radiation at wavelengths of 290-315 nm; the absorbed energy causes breakage and rearrangement of its chemical bonds, resulting in a conversion to previtamin D_3 (Tsiaras & Weinstock 2011). The previtamin D_3 thereafter undergoes thermally induced transformation to vitamin D_3 (Tsiaras & Weinstock 2011). Vitamin D from foods and supplements (D_2 or D_3) is incorporated into chylomicrons, absorbed into the lymphatic system, and transported in venous circulation (Holick 2008, Tsiaras & Weinstock 2011). The vitamin D synthesized is biologically inactive until it undergoes two hydroxylation processes (Ross *et al.* 2011) (Figure 2). The vitamin D in the blood is transported by vitamin D binding protein to the liver, where it is metabolized by an enzyme, 25-hydroxylase, i.e. cytochrome P450 2R1 (CYP2R1), and hydroxylated to 25-hydroxyvitamin D [25(OH)D; calcidiol]. The 25(OH)D, which is the major circulating form of vitamin D, re-enters the circulation and is converted in the kidney by another enzyme, 25(OH)D-1α-hydroxylase, i.e. cytochrome P450 27B1 (CYP27B1), to hormonal form 1,25-dihydroxyvitamin D [$1,25(OH)_2D$; calcitriol] (Ross *et al.* 2011, Tsiaras & Weinstock 2011). The $1,25(OH)_2D$ is the active form of vitamin D and its production is regulated by factors such as serum phosphorus, serum calcium and parathyroid hormone (PTH) concentrations (Ross *et al.* 2011). The production of the active metabolite calcitriol occurs at the fall of serum calcium concentration, which stimulates the secretion of PTH from the parathyroid gland for hydroxylation of 25(OH)D to $1,25(OH)_2D$ by enzyme CYP27B1 in the kidney (Christakos *et al.* 2013).

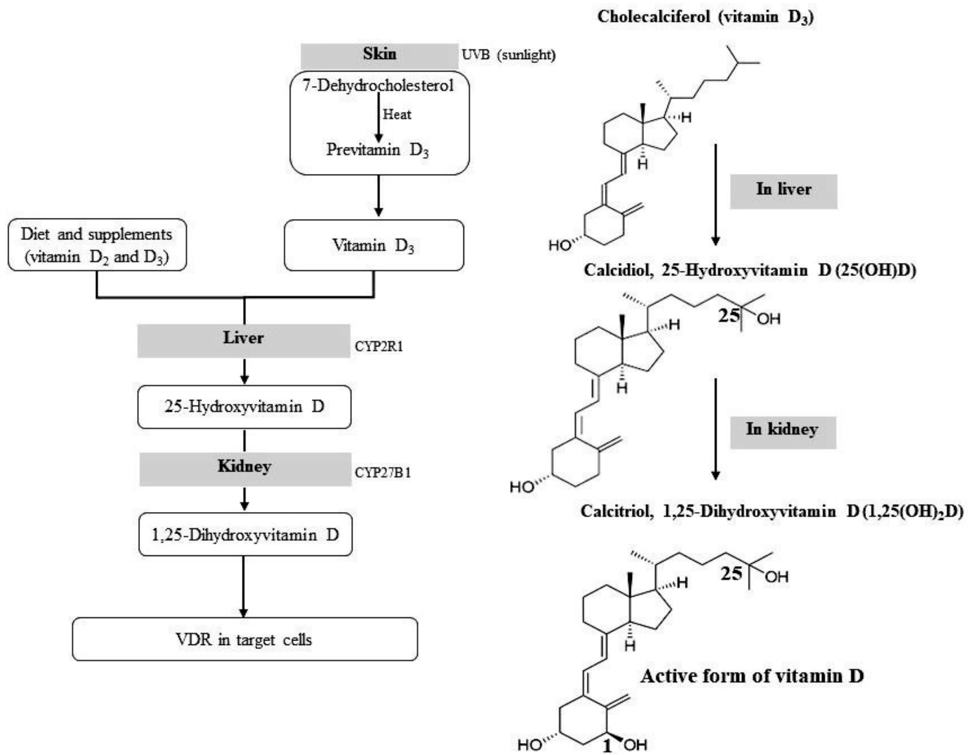

Figure 2. *Vitamin D synthesis and metabolism.*

2.2.3 Functions of vitamin D

The principal function of calcitriol, the biologically active form of vitamin D, is to maintain the blood concentration of calcium and phosphorus, which is required for bone formation, bone mineralization, and neuromuscular function (Ross *et al.* 2011, Tsiaras & Weinstock 2011). Besides the calcium and phosphorus homeostasis, roles of vitamin D have been discovered in many organs throughout the human body, i.e. influencing the immune system, cellular metabolism, cardiovascular systems, and muscle and brain systems (Norman & Bouillon 2010, Stöcklin & Eggersdorfer 2013). The active $1,25(OH)_2D$ as a hormone interacts with a nuclear vitamin D receptor (VDR) in target tissues such as the small intestine, osteoclasts in bone and renal tubular cells in kidneys (Holick 2008). The classic function of vitamin D in maintenance of calcium and phosphorus homeostasis is achieved through three different mechanisms: (1) calcitriol stimulates the intestinal absorption of calcium and phosphorus; (2) with PTH, it increases the number of osteoclasts in the bone and thus results in mobilization of calcium and phosphorus, and their release into the blood; and (3) together with PTH, it stimulates tubular reabsorption of calcium and phosphorus in the kidney (Holick 2008, Ross *et al.* 2011). Owing to the presence of VDR in the nucleus of various tissues and cells in the body (Ross *et al.* 2011), the actions of vitamin D are not limited to the tissues regulating calcium and phosphorus metabolism. Expression of the enzyme CYP27B1 has been found in many tissues besides the kidney, thus making calcitriol production possible in extra-renal tissues such as placenta, pancreas, prostate, breast, skin, brain, and immune cells (Norman & Bouillon 2010, Christakos *et al.* 2013). Hence, significance of vitamin D has been observed in overall health as well as different diseases, including autoimmune diseases (such as multiple sclerosis and type 1 diabetes), CVD, neurodegenerative diseases, and cancer (Tsiaras & Weinstock 2011, Christakos *et al.* 2013, Lockaua & Atkinson 2018).

2.3 Vitamin D status

2.3.1 Vitamin D assessment

Circulating S-25(OH)D concentration is widely considered the best marker for assessing vitamin D status (Holick 2007a, Ross *et al.* 2011). Its acceptance as the most suitable metabolite in determining vitamin D status arises from its ability to reflect net vitamin D input from total intake (foods and supplements) and cutaneous production (Holick 2006, Ross *et al.* 2011). In addition, among the vitamin D derivatives, including the biologically active 1,25$(OH)_2D$ with a half-life of 4-6 hours, S-25(OH)D is most abundant in the blood circulation and has the longest half-life of about 2-3 weeks (Zitterman 2003, Holick 2009). Serum 1,25$(OH)_2D$ is not considered a useful marker of vitamin D status due to its less circulating concentrations, short half-life, and inability to detect insufficiency and deficiency as a result of its usual normal or even elevated concentration, which is associated with increased PTH levels (Holick 2009). Based on these characteristics of S-25(OH)D, it is used to define vitamin D status in terms of deficiency, insufficiency, sufficiency, and toxicity.

Over the years, different clinical assays have been used to measure S-25(OH)D. The two major methods employed are immunological assays and chemical assay techniques (Atef 2018). The immunoassay methods, which are the most popular methods (Wallace *et al.* 2010), include chemiluminescence immunoassays (CLIA), radioimmunoassay (RIA), enzyme-linked immunosorbent assay (ELISA), and IDS enzyme immunoassay (EIA), while chemical assay techniques comprise of high-performance liquid chromatography (HPLC) and liquid chromatography-tandem mass spectrometry (LC-MS/MS) (Wallace *et al.* 2010, Atef 2018). The RIA and CLIA measure total 25(OH)D concentrations with the ability of recognizing 25$(OH)D_2$ equally as well as 25$(OH)D_3$ (Holick 2007a, Holick 2009). Nevertheless, the reliability of some of the immunological assays, such as RIA, have been questioned due to variation in results between laboratories and inability to distinguish between 25(OH)D and other hydroxylated metabolites of vitamin D, including 24,25-dihydroxyvitamin D, which frequently results in overestimated total 25(OH)D concentrations (Holick 2007a, Holick 2009, Binkley *et al.* 2014). The HPLC and LC-MS/MS assays quantitatively measure 25$(OH)D_2$ and 25$(OH)D_3$ separately; total 25(OH)D concentrations can be easily reported as the sum of the two forms (Wallace *et al.* 2010, Atef 2018). However, LC-MS/MS is regarded as the “gold standard” assay for measuring 25(OH)D based on its high specificity, high sensitivity, and good reproducibility (Ross *et al.* 2011).

With the discrepancies in the range of the available methods (including limitations) for measuring 25(OH)D and existing variations in results, defining patients' vitamin D status becomes complicated, affecting the clinical managements of patients (Atef 2018). In addition, comparison of 25(OH)D results from different laboratories and pooling of results from different research in systematic reviews are problematic (Binkley *et al.* 2014). To ensure the analytical reliability of 25(OHD), the Vitamin D External Quality Assessment Scheme (DEQAS) was incorporated into vitamin D assessment worldwide since 1989 (Carter *et al.* 2018). The scheme evaluates the performance of assays used in measuring total S-25(OH)D through a consensus mean based on the all-laboratory trimmed mean (ALTM) (Carter *et al.* 2018). Furthermore, concerns about the need to standardize 25(OH)D measurement led to international joint efforts that established the Vitamin D Standardization Program (VDSP) as a reference method in 2010 (Sempos *et al.* 2012, Binkley *et al.* 2014). The VDSP, the goal of which is to ensure accuracy in 25(OH)D) concentration measurements and comparison regardless of time, location, and assay methods for improvement of clinical and public health practice world-wide (Sempos *et al.* 2012), has improved assessment of vitamin D status (Cashman *et al.* 2016).

2.3.2 Definitions: categories of vitamin D status

Despite of no standard consensus cut-off points for S-25(OH)D regarding the classification of vitamin D status, especially defining adequate status, some definitions are commonly accepted in research (Table 4). Generally, S-25(OH)D concentration below 25 nmol/L is considered 'deficient', a lower limit threshold set with regard to prevention of rickets, osteomalacia, and poor bone health in 97.5% of the population (Spiro & Buttriss 2014). The current NNR reference values for S-25(OH)D concentration derive from IOM evidence-based suggestions (Ross *et al.* 2011, Nordic Council of Ministers 2014). According to IOM in relation to bone health (Ross *et al.* 2011), S-25(OH)D concentration of 40 nmol/L is defined as the value that covers vitamin D requirements of 50% of the population. The sufficient threshold of $\geq$ 50 nmol/L is considered as the concentrations that will meet the needs of nearly all (97.5%) individuals (Ross *et al.* 2011).

Table 4. *Categories of vitamin D status according to S-25(OH)D concentration thresholds.*

S-25(OH)D (nmol/L)	Vitamin D status	Health implications	Agency
<30	Deficient	Associated with rickets in infants and children and osteomalacia in adults	IOM[1]
30 - <50	Insufficient	Insufficient for bone and overall health in healthy individuals	IOM[1]
≥50	Sufficient	Sufficient for bone and overall health in healthy individuals	IOM[1], NNR[2]
75-120		Optimal target concentration in an osteoporosis patient	Current Care Guidelines[3]
≥125	Toxicity	Associated with no increased benefits and raise concerns for potential adverse effects (i.e. toxicity)	IOM[1]

[1]Institute of Medicine

[2]Nordic Nutrition Recommendations

[3]Care Guidelines for osteoporosis treatment in Finland

2.3.3 Factors affecting vitamin D status and groups at risk

There are various factors influencing vitamin D status. In a broad view, these factors are related to vitamin D endogenous production, dietary intake, absorption, metabolism, and bioavailability. The endogenous dermal synthesis of vitamin D is sufficient throughout the year at latitudes below 35° north and above 35° south, while UVB radiation is limited for vitamin D_3 synthesis at higher latitudes during the winter season (Tsiaras & Weinstock 2011). For instance, cutaneous vitamin D_3 synthesis is not possible from October through March in Helsinki, Finland (latitude 60°N) (Lamberg-Allardt 1984). Seasonal variation in UVB radiation, especially at northern latitudes, affects vitamin D synthesis in the skin, as optimal amounts are produced in summer compare with winter, when little or no production occurs (Laird *et al.* 2010). Moreover, time of day for sunlight exposure is important; maximum UVB radiation intensity is reached at midday in the summer (Webb & Engelsen 2006, Tsiaras & Weinstock 2011).

Increase in the skin pigment melanin reduces cutaneous vitamin D_3 production (Zitterman 2003, Holick 2008) and is thus related to the time spent outdoors. The required time of sunlight exposure for sufficient vitamin D synthesis is determined by skin colour; people with darker skin (e.g. African descent) require a longer (about six fold) UV exposure period than fair-skinned (Caucasian) individuals at high latitudes (Webb & Engelsen 2006). While melanin of dark pigmented skin is a natural sunscreen against damaging effects from excessive exposure to UV radiation (Holick 2008), use of sunscreen reduces vitamin D synthesis because it prevents UV light from reaching the skin (Ross *et al.* 2011). In addition, type and style of clothing influence the amount of cutaneous vitamin D_3 synthesized, as wearing thick fabrics and clothes covering the entire body reduce the intensity of UV radiation on the skin (Tsiaras & Weinstock 2011, Ross *et al.* 2011). Other factors affecting endogenous production of vitamin D include sun exposure habit, amount of skin exposed, free living/institutionalization, air pollution, cloud cover, and urban environments with tall buildings blocking the sunlight (Ross *et al.* 2011).

Skin production of vitamin D is affected by age, while its bioavailability is related to both age and BMI (Tsiaras & Weinstock 2011). Older adulthood has been associated with increased risk of vitamin D insufficiency due to a decline in skin 7-dehydrocholesterol content, likelihood of spending more time indoors, and possibility of insufficient vitamin D intakes from foods and/or supplements (Tsiaras & Weinstock 2011, Ross *et al.* 2011). UVB-induced and dietary vitamin D is stored in adipose tissue; the inverse relationship between BMI and S-25(OH)D concentrations suggest a reduction in bioavailability of vitamin D due to large fat mass in obese individuals (Wortsman *et al.* 2000, Tsiaras & Weinstock 2011). Consumption of vitamin D-rich foods (natural/fortified foods) influences vitamin D status; this depends on food habits and ability to include the few available dietary sources into the regular diet in sufficient amounts (Lamberg-Allardt 2006, Holick 2006). In the situation of limited sun exposure and insufficient vitamin D intake from food, use of supplements containing vitamin D is important to meet the daily requirement (Lamberg-Allardt 2006).

Disease of organs involving in the absorption and metabolism of vitamin D, such as liver, intestine and kidney diseases can significantly affect vitamin D status. Reduction in vitamin D absorption has been observed in patients with intestinal malabsorption, liver failure, celiac disease, chronic pancreatitis, and gastric bypass, while chronic renal failure results in decreased concentration of serum of 1,25-dihydroxyvitamin D (Tsiaras & Weinstock 2011). Hence, these disease states are often associated with low levels of 25(OH)D (Tsiaras & Weinstock 2011).

Besides age and BMI, some other socio-demographic and lifestyle factors, such as sex, education, smoking, alcohol consumption, and physical activity, have been associated with vitamin D status. The link between outdoor activities and sun exposure may explain the positive associations that have been observed between physical activity and S-25(OH)D concentration (Looker 2007, Thuesen *et al.* 2012, Yao *et al.* 2017). By contrast, the indirect association of unhealthy dietary habits and smoking is a suggestive factor for low

S-25(OH)D among smokers (Shinkov *et al.* 2015, Kassi *et al.* 2014). However, not all associations are consistent and reasons for some of them are unclear.

Genetic factors have also been identified in association with vitamin D status, as single-nucleotide polymorphisms (SNPs) in the vitamin D binding protein (DBP) and in the enzymes involved in the metabolism of vitamin D and its metabolites determine the S-25(OH)D concentration (Wang *et al.* 2010, Elnenaei *et al.* 2011, Didriksen *et al.* 2013). According to Shea *et al.* (2009), up to 28% of inter-individual differences in S-25(OH)D concentrations possibly occur due to genetic factors. Altogether, the SNPs, namely 7-dehydrocholesterol reductase (DHCR7), CYP27B1, CYP2R1, and 24-hydroxylase, i.e. cytochrome P450 24A1 (CYP24A1), are responsible for 5% of the variation in S-25(OH)D (Wang *et al.* 2010, Signorello *et al.* 2011, Lips *et al.* 2019). Based on several factors affecting vitamin D status, some groups of people have been identified as being at increased risk of vitamin D insufficiency (Table 5).

Table 5. *Groups at risk of low vitamin D status.*

Group	Causes
Breastfed infants	Low content of vitamin D in human milk[1]
Vegetarians	Little or no vitamin D intake from diets[1,2]
People living at high latitudes	Limited sunlight exposure during winter period[3,4]
Elderly populations	Reduction in vitamin D synthesis in the skin and likelihood of spending more time indoors[1]
Homebound individuals, women wearing concealing clothing and indoor workers	Limited sun exposure[1,4]
Obese individuals	Decrease in bioavailability of vitamin D due to large fat mass[1,4,5]
People with dark skin	Reduction in cutaneous vitamin D production due to increased skin pigment melanin[1,3,6]
Individuals with intestinal malabsorption or disorders of parathyroid, liver, or kidney	Reduction in vitamin D absorption and metabolism[4]

[1]Ross *et al.* 2011; [2]Crowe *et al.* 2011; [3]Webb & Engelsen 2006; [4]Tsiaras & Weinstock 2011; [5]Wortsman *et al.* 2000 [6]Holick 2008

2.3.4 Outcomes of low vitamin D status

Adequate vitamin D status is essential for skeletal health at all ages, in terms of bone development and growth in children and bone maintenance in adults. Nevertheless, there are growing concerns about the effects of low S-25(OH)D on several non-skeletal disorders (Spiro & Buttriss 2014). Hence, low vitamin D status or hypovitaminosis D, which includes both the state of vitamin D deficiency and insufficiency, is a public health concern. The major outcome of vitamin D deficiency manifests as rickets in children and osteomalacia in adults. Rickets is a condition of under-mineralization of bones in infants and children due to poor absorption of calcium in the absence of adequate vitamin D; it is characterized by softened skull bones, bowed legs, knocked knees, rib-cage collapse, and deformed pelvic bones (Ross *et al.* 2011, Wranicz & Szostak-Węgierek 2014). Osteomalacia is the adult equivalent of rickets and it occurs because of demineralization of bones; a failure occur in sufficient mineralization of the newly deposited bone matrix (Ross *et al.* 2011). This results in bone pains, proximal muscle weakness and increased frequency of fractures (Ross *et al.* 2011, Grant & Boucher 2011).

In adults, vitamin D insufficiency, which is associated with impaired calcium metabolism, may result in secondary hyperparathyroidism, increased bone turnover, bone loss, osteoporosis, fractures and risk of falls (Holick 2006, Ross *et al.* 2011). The non-skeletal effects of low vitamin D status have been observed in different conditions, types of cancer, and other chronic diseases (Rejnmark *et al.* 2017, Bouillon *et al.* 2019). In a systematic review of findings from randomized controlled trials (RCTs) included in meta-analyses, beneficial effects of vitamin D supplementation were suggested for the risk of non-skeletal outcomes such as depression, blood pressure, respiratory tract infections, and all-cause mortality (Rejnmark *et al.* 2017). Nevertheless, findings from the observational studies were not substantially supported by the systematic review. Furthermore, results from meta-analysis and systematic reviews support earlier findings in observational studies regarding asthma, wheeze, and respiratory infection as outcome of low vitamin D status in children (Christensen *et al.* 2017, Shen *et al.* 2018). The controversial and inconclusive findings of observational studies on vitamin D status among children are largely due to poor methodological quality (Nurmatov *et al.* 2011). Inadequate consideration of confounding and effect modification has been identified in many studies investigating the potential effects of diet on the development of childhood asthma and allergic disease (Nurmatov *et al.* 2012). In general, strong evidence on the effects of low 25(OH)D is still lacking due to most RCTs being carried out in populations without a high prevalence of low vitamin D status (Rejnmark *et al.* 2017).

2.3.5 Effect of vitamin D supplementation on S-25(OH)D

Impacts of vitamin D supplementation on S-25(OH)D concentrations are well documented, especially in RCTs (Cranney *et al.* 2007, Autier *et al.* 2012). Table 6 presents some studies carried out among immigrant populations in Nordic countries. According to Mazahery & von Hurst (2015), use of vitamin D supplements is currently the best method for treating vitamin D deficiency and maintaining adequacy; it is easy, effective, and cost-effective. The use of supplements generally results in increased S-25(OH)D concentrations; a meta-regression revealed an average increase in S-25(OH)D concentrations of 1.95 nmol/L per microgram of daily vitamin D_3 supplement, without the concomitant use of calcium supplements (Autier *et al.* 2012). Nonetheless variations exist in individual response to vitamin D supplementation based on different factors such as type, dosage, baseline S-25(OH)D concentrations, BMI/body fat percentage, and duration of supplementation, thus findings vary considerably (Ross *et al.* 2011, Mazahery & von Hurst 2015). Hence, vitamin D supplementation does not comply with the one-size-fits-all approach (Mazahery & von Hurst 2015). Other important factors that may influence response to a given dose of vitamin D include ageing, ethnicity, calcium intake, genetics, dietary fat content and composition, some diseases and medications, oestrogen use, and season (Mazahery & von Hurst 2015).

Effects of baseline S-25(OH)D concentrations and BMI on dose-response rate are well established; higher dose response is often reported among individuals with low baseline S-25(OH)D concentrations, but this decreases with increasing BMI (Didriksen *et al.* 2013, Scragg 2018). Both daily or periodical high-dose and daily low-dose of vitamin D have been effective in achieving adequate concentrations (Ish-Shalom *et al.* 2008, Imga *et al.* 2018). However, the issues of optimal dose and frequency of supplementation remain controversial, especially regarding safety and effectiveness, in increasing S-25(OH)D concentrations and maintaining sufficiency over the long run (Chel *et al.* 2008, Ish-Shalom *et al.* 2008, Imga *et al.* 2018). The non-significant effect of increasing vitamin D doses (ranging from 10 to 120 µg/d) on bone mineral density (BMD), in a recent RCT among Caucasians and African Americans with low baseline S-25(OH)D (Smith *et al.* 2018), suggested that high-doses are without benefit, except among those who are severely deficient and for treatment of osteomalacia and osteoporosis (Reid 2018). In addition, a systematic review, meta-analysis, and trial sequential analysis conducted by Bolland *et al.* (2018) showed no differences between the effects of higher and lower doses of vitamin D on fractures, falls, or BMD.

Generally, vitamin D_2 is considered less potent than vitamin D_3 in maintaining S-25(OH)D concentrations owing to its shorter circulating half-life (Armas *et al.* 2004, Autier *et al.*

2012, Tripkovic *et al.* 2012). However, some studies have found vitamin D_2 to be equally as effective as vitamin D_3 (Biancuzzo *et al.* 2010, Fisk *et al.* 2012). The differences in the effectiveness between vitamin D_2 and D_3 were confirmed by Logan *et al.* (2013) and Itkonen *et al.* (2016b), as S-25(OH)D_3 declined rapidly among D_2-treated subjects. Differences in S-25(OH)D are often observed between dark-skinned and Caucasian populations, with lower concentrations among dark-skinned individuals (Aloia *et al.* 2008, Gallagher *et al.* 2014, Cashman *et al.* 2016). However, studies showed that response of S-25(OH)D to vitamin D supplementation between dark-skinned and Caucasian persons is independent of race or ethnicity (Aloia *et al.* 2008, Gallagher *et al.* 2014).

Table 6. *Studies investigating the effect of vitamin D supplementation on 25(OH) concentrations among immigrants in Nordic countries.*

Authors, country, latitude	**Duration, season**	**Population, n**	**Participants, sex, age**	**Interventions**	**Mean (median[1]) baseline 25(OH)D (SD/range/25th&75th percentile[1] nmol/L)**	**Mean (median[1]) Δ 25(OH)D (SD/range[2]/25th&75th percentile[1] nmol/L)**
Andersen *et al.* 2008a[1] Denmark, 55ºN	1 year, all seasons	Pakistani, n=199	Men, 18-64 years	10 µg vitamin D_3/d	22.9 (12.6, 28.2)	16.5 (18.4, 20.0)
				20 µg vitamin D_3/d	18.9 (13.6, 29.2)	35.8 (31.6, 35.9)
				Placebo	20.0 (15.0, 25.2)	-0.9 (-1.9, -2.6)
			Women, 18-64 years	10 µg vitamin D_3/d	9.95 (6.9, 14.3)	30.95 (30.5, 33.4)
				20 µg vitamin D_3/d	14.0 (8.3, 17.5)	32.2 (30.3, 35.7)
				Placebo	11.7 (7.5, 19.4)	-1.6 (0.9, -3.3)
Knutsen *et al.* 2014 Norway, 60ºN	16 weeks, winter	**Immigrants, n=251** South Asian, n=95 Middle-East/Northern African, n=36 Sub-Saharan African, n=120	Men and women, 18-50 years	10 µg vitamin D_3/d	27.0 (17.0)	16.0 (20.0)
				25 µg vitamin D_3/d	27.0 (15.0)	25.0 (22.0)
				placebo	27.0 (15.0)	-2 (10)
Osmancevic *et al.* 2016[1,2] Sweden, 57ºN	12 weeks, autumn and winter	Somali, n=114	Women, 18-56 years	20 µg vitamin D_3/d	19.0 (9-72)	18.0 (6-29)
				40 µg vitamin D_3/d	23.0 (9-54)	29.0 (17-42)
				placebo	17.0 (9-53)	No change

2.3.6 Vitamin D status in Finland

Vitamin D status in the general Finnish population has greatly improved over the years (Jääskeläinen *et al.* 2017, Raulio *et al.* 2017), especially since the introduction of fortification policy in 2003 and the subsequent increment of the fortification scheme in 2010 (Ministry of Trade and Industry 2002, National Nutrition Council 2010). The vitamin D fortification scheme was increased from 0.5 µg to 1 µg/100 g in fluid milk products and respective plant-based alternatives, and from 10 µg to 20 µg/100 g in fat spreads. However, the fortification policy did not cover organic products (dairy or plant-based) (National Nutrition Council 2010), except for the mandatory fortification of homogenized organic fat-free milk with 1 µg/100 g (Ministry of Agriculture and Forestry 2016, Itkonen *et al.* 2018).

The latest national representative studies reported adequate vitamin D status (S-25(OH)D >50 nmol/L) for the majority (77-91%) of Finnish adults (Jääskeläinen *et al.* 2017, Raulio *et al.*2017). In 2011, the mean concentration of S-25(OH)D in the Finnish general population was reported to be 65 and 66 nmol/L for men and women, respectively (Jääskeläinen *et al.* 2017). The average daily dietary intake (from food only) contributing to the vitamin D status among the Finnish adult population is documented in the recent national dietary survey (FinDiet 2017) as 13 µg for men and 10 µg for women (Valsta *et al.* 2018). The proportion of daily vitamin intake from vitamin D-fortified fat spreads was 37% for men and 32% for women; the contribution from vitamin D-fortified dairy products was 26% for men and 25% for women, and intake from fish was 20% for men and 22% for women (Valsta *et al.* 2018). The proportion of supplement users among Finnish men and women was 40% and 57%, respectively, and their mean total intake was 36 µg for both men and women (Valsta *et al.* 2018). Nevertheless, the satisfactory vitamin D status observed in Finland does not include the immigrant populations, and knowledge about the vitamin D status among immigrants living in Finland is still limited. An earlier study among immigrants in Finland reported lower S-25(OH)D concentrations and higher prevalence of low vitamin D status (S-25(OH)D <50 nmol/L) among Somali and Bangladesh immigrant women than among Finnish women (Islam *et al.* 2012).

2.3.7 Vitamin D status among immigrants

Compared with host populations, poor vitamin D status is commonly observed in studies (Table 7) of non-Western immigrants and asylum seekers. Concerns about the vitamin D status of this group of people, particularly dark-skinned individuals living in Western countries, were highlighted by the IOM (Ross *et al.* 2011). High risk of vitamin D deficiency has been identified among immigrants with Asian, African, or Middle Eastern background living in the Nordic countries (Van der Meer et al. 2011, Spiro & Buttriss 2014, Cashman *et al.* 2016) of Finland (Islam *et al.* 2012), Denmark (Andersen *et al.* 2008a, Andersen *et al.* 2008b, Grønborg *et al.* 2019), Norway (Meyer *et al.* 2004, Holvik *et al.* 2005, Madar *et al.* 2009) and Sweden (Andersson *et al.* 2013, Bärebring *et al.* 2016, Granlund *et al.* 2016, Osmancevic *et al.* 2016). The situation is likely to be severe among refugees who may suffer malnourishment upon arrival (Wishart *et al.* 2007). Migration from countries closer to the equator to higher northern or southern latitudes where sunlight is less effective during the day for vitamin D synthesis, especially in the winter period, is a major factor contributing to vitamin D deficiency among immigrants (Lips and de Jongh 2018). Furthermore, pigmented skin, limited exposure to sunlight because of cultural or religious practices such as skin-covering clothing style and lower vitamin D intake, which may results from dietary habits that limit the use of dietary sources, increases vitamin D deficiency among immigrants (Granlund *et al.* 2016, Lips and de Jongh 2018, Guo *et al.* 2018). For instance, Wändell (2013) observed uncommon consumption of fatty fish among non-Western immigrants living in the Nordic countries.

Low use of vitamin D supplements has also been observed among immigrants from non-Western countries (Andersson *et al.* 2013, Osmancevic *et al.* 2016, Lips and de Jongh 2018). As an outcome of vitamin D deficiency, nutritional rickets is still a concern among children in Western countries, with a higher prevalence observed among immigrant children in Denmark, the majority of whom are girls using veils (Beck-Nielsen *et al.* 2009). However, incidence of rickets is rare in the Norwegian population because children are offered free vitamin D drops at child health clinics (Madar *et al.* 2017, Meyer *et al.* 2017). Besides rickets in children, other health outcomes of low vitamin D status that have been observed among immigrant adults include muscle pain in immigrant women living in Sweden (Andersson *et al.* 2013, Englund *et al.* 2017). Likewise, lower forearm BMD was reported in Bangladeshi and Somali immigrant women, in association with low S-25(OH)D, than in Finnish women (Islam *et al.* 2012). Risk of obesity-related chronic disease, such as T2D and CVD, has been suggested in association with vitamin D insufficiency among ethnic minorities, but such findings are yet to be established (Renzaho *et al.* 2011).

Table 7. *Studies examining vitamin D status among immigrant populations in Nordic countries.*

Authors	**Study design, year of data collection, season**	**Population, n**	**Participants, sex, age**	**Mean (median*) vitamin D intake from food (µg/d) (SD/95% CI/25th&75th percentile*)**	**Supplement users (%)**	**Total mean (median*) vitamin D intake (µg/d) (SD/95% CI/25th&75th percentile*)**	**Mean serum or plasma 25(OH)D concentration (SD/95% CI/range) nmol/L**
Denmark							
Andersen *et al.* 2008b [a*]	Cross-sectional, 2002, all seasons	Pakistani, n=210	Men (n=95), 18-64 years	2.2 (0.8, 11.2)	25	NA	20.7 (7.0, 56.0)
			Women (n=115), 18-53 years	1.7 (0.5, 6.9)	22	NA	12.0 (3.6, 55.9)
Grønborg *et al.* 2019*	RCT[b], 2016, winter	Pakistani, n=70	Women, 18-50 years	1.1 (1.0, 2.0)	61	13.0 (6.8, 29.3)	46.9 (22)
		Danish, n=66	Women, 18-50 years	1.5 (1.0, 2.0)	15	2.9 (1.8, 9.0)	49.6 (18)
Finland							
Islam *et al.* 2012	Cross-sectional, 2008, late winter	Bangladeshi, n=34	Women, 20-48 years	NA	9	NA	42·9 (16.1)
		Somalis, n=48	Women, 20-48 years	5.0 (2.0)	10	NA	36·8 (11.8)
		Finnish, n=61	Women, 20-48 years	4.6 (2.0)	50	NA	54·1 (19.1)
Norway							
Meyer *et al.* 2004	Cross-sectional, 2000-2001, summer-early winter	Pakistani, n=177	Men and women, 30-75 years	NA	NA	NA	25.0 (13.6)
		Norwegian, n=869					74.8 (23.7)
Holvik *et al.* 2005*	Cross-sectional, 2000-2001, late	**Immigrants, n=1000**	Men and women, 20-60 years	NA	13[c]	NA	

	winter-autumn	Turkish (n=188)					29.5 (21, 38)
		Sri Lankan (n=310)					30.0 (22, 39)
		Iranian (n=199)					29.0 (21, 39)
		Pakistani (n=191)					22 (18, 29)
		Vietnamese (n=112)					38 (28, 47)
Madar *et al.* 2009	RCT[b], 2004-2006, all seasons	Immigrants, n=80	Women, 28 years[d]	NA	NA		
		Pakistani (n=45)				13	26.7 (16.5)
		Turkish (n=25)				4	26.1 (14.1)
		Somali (n=10)				4	21.5 (12.1)
Sweden							
Andersson *et al.* 2013*	Cross-sectional, 2009, late winter	Middle Eastern and Africans, n=31	Women, 18 -75 years	3.1 (2.0, 4.4)	NA	3.1 (2.0, 4.7)	22.2 (13.7, 28.6)
		Swedish, n=30	Women, 18 -75 years	5.1 (3.7, 6.4)		5.8 (4.0, 9.0)	51.5 (39.6, 66.5)
Granlund *et al.* 2016	Cross-sectional, 2009-2010, autumn-summer	Middle Eastern, n=139	Men and women, 25-65 years	NA	24	NA	42.8 (16.0)
		Africans, n=77	Men and women, 25-65 years		25		37.7 (17.4)

[a]Median (2½, 97½) percentiles; [b]Baseline data; [c]Cod liver oil supplements; [d]Mean age
NA, not available.

3 AIMS OF THE THESIS

The overall aim of this thesis was to assess diet and vitamin D status among immigrants of Russian, Somali, and Kurdish background. In addition, this thesis investigated whether ethnic differences exist between Somali and Finnish women in the response of serum 25-hydroxyvitamin D (S-25(OH)D) to vitamin D_3 supplementation.

Specific aims were as follows:

1. To evaluate the consumption of healthy foods and to examine the association between socio-demographic factors and food consumption among Russian, Somali, and Kurdish participants in the Migrant Health and Wellbeing Study – **Study I**
2. To study the vitamin D status (S-25(OH)D), its determinants, and consumption of major dietary sources of vitamin D among Russian, Somali, and Kurdish participants in the Migrant Health and Wellbeing Study, and to compare the vitamin D status of the immigrant groups with that of the general Finnish population of the Health 2011 Survey – **Study II**
3. To investigate, through a RCT, whether differences exist between Somali (East African) and Finnish (Caucasian) women in response of S-25(OH)D to vitamin D_3 supplementation, and to examine ethnic differences in the two groups of women in vitamin D status in terms of S-25(OH)D concentration and vitamin D intake from the diet and supplements – **Study III**

4 SUBJECTS AND METHODS

4.1 Study population and design

This thesis is based on three different datasets: (1) the Migrant Health and Wellbeing Study (Maamu Study) (**Studies I and II**), (2) the Health 2011 Survey (Health 2011) (**Study II**), and (3) the Marwo-D intervention study (**Study III**). Studies I and II were cross-sectional studies, while Study III was a randomized controlled trial. The studies are described in detail in the subsequent sub-sections. A summary of the study population, design, datasets and inclusion criteria used in the three studies is presented in Table 8.

Table 8. *Summary of study population and design (Studies I-III).*

Study	Dataset	Design	n, age	Inclusion criteria
I	Maamu Study	Cross-sectional	1372 (527 Russians, 337 Somalis, and 508 Kurds), aged 18-64 years	Men and women Responded to at least one dietary question
II	Maamu Study and Health 2011	Cross-sectional	1310 immigrants (446 Russians, 364 Somalis, and 500 Kurds), aged 18-64 years 798 Finns, aged 30-64 years	Men and women S-25(OH)D concentration available
III	Marwo-D intervention study	Randomized controlled trial Intervention groups: Placebo, 10 µg, 20 µg	191 screened, aged 21-64 years 147 randomized (72 Somalis, and 75 Finns), aged 21-64 years Placebo: 28 Somalis, 24 Finns 10 µg: 26 Somalis, 26 Finns 20 µg: 18 Somalis, 25 Finns	Non-pregnant and non-breastfeeding women Somali or Finnish origin BMI ≤40 kg/m^2 S-25(OH)D concentration >30 nmol/L but <100 nmol/L

4.1.1 Maamu Study (I and II)

Data from the Maamu Study were used in Studies I and II. The Maamu Study is the first population-based health interview and examination survey conducted among immigrants in Finland. The study population consists of three different immigrant groups, which are part of the largest foreign-born populations in Finland (Statistics Finland 2019): persons of Russian, Somali, and Kurdish origin. These groups were selected to the Maamu Study because: (1) the Russian origin population is the largest immigrant group in Finland and (2) Somali (fourth largest) and Kurdish (sixth largest) origin populations are important and potentially vulnerable groups due to involuntary migration experience (Castaneda *et al.* 2012, Statistics Finland 2019). Altogether, 3000 adults (1000 persons from each immigrant group) were randomly selected from the National Population Register and invited to the study. Maamu data were collected between 2010 and 2012 in the cities of Helsinki (60°N), Espoo (60°N), Vantaa (60°N), Turku (60°N), Tampere (62°N), and Vaasa (63°N). The Maamu Study was coordinated by the Finnish Institute for Health and Welfare (THL), with the aim of providing comprehensive information on health, well-being, and needs and use of health services among the three major migrant groups in Finland (Castaneda *et al.* 2012).

In Study I, data from participants who answered at least one of the dietary questions in the interview were used. Of those invited, the Study I sample comprised 53% of Russian (n=527), 34% of Somali (n=337), and 51% of Kurdish (n=508) participants, while the Study II sample comprised 45% of Russian (n=446), 36% of Somali (n=364), and 50% of Kurdish (n=500) participants with available data on S-25(OH)D concentration. These immigrant groups are subsequently also referred to as Russians, Somalis, and Kurds (Table 8).

4.1.2 Health 2011 (II)

Data from the Health 2011 were included in Study II as comparison data from the general population in Finland. The Health 2011 is a national representative survey carried out among Finnish adults, living in mainland Finland, with the main objective of examining the health and well-being of the general Finnish population. The participants (n=2275) of the Health 2011 were selected to the general Finnish population reference group from the corresponding six cities where the Maamu Study was conducted. Data of the Health 2011 were collected through questionnaires, interviews, and a comprehensive health examination. The Health 2011 was also conducted by the THL in the same timeframe (2011) and with a protocol comparable to the Maamu Study (Härkänen 2013, Lundqvist & Mäki-Opas 2016).

In Study II, 35% of the general Finnish population reference group (n=798) with available data on S-25(OH)D concentration, aged 30-64 years, were included for comparison, and they are subsequently also referred to as Finns (Table 8).

4.1.3 Marwo-D intervention study (III)

The Marwo-D intervention study (Study III) was a 5-month, randomized, placebo-controlled, dose-response, trial implemented within the European Union (EU)-funded research project "Food-based solutions for optimal vitamin D nutrition and health through the life cycle" (ODIN; FP7-613977-ODIN; www.odin-vitd.eu). The study was part of ODIN's Work Package 6 with the overall objective of delivering the proof of efficacy and safety of food-based solutions to prevent vitamin D deficiency by focusing on EU-resident adults most at risk of vitamin D deficiency due to skin colour, sun exposure practices, or dietary habits.

Women of Somali (East African) and Finnish (Caucasian) background aged 21-64 years were enrolled from the Helsinki metropolitan area (60ºN) of Southern Finland. Some of them were recruited from the register of shortlisted subjects for participation in the Maamu Study. Out of 191 subjects screened for eligibility, 147 (77% of those screened) met the inclusion criteria and were randomized into three supplementation groups: placebo or 10 µg or 20 µg vitamin D_3/d. The subjects were studied during an extended winter period (December 2014 and May 2015) at the Department of Food and Environmental Sciences, University of Helsinki, Finland. The study protocol included questionnaires, interviews, and serum measurements. Altogether 125 subjects (85% of those randomized) completed the study and 22 subjects (15%) discontinued after randomization for the following reasons: withdrawal (n=8), lost to follow-up (n=8), and ineligible due to pregnancy (n=6). The consort diagram showing participants' recruitment and randomization is presented in Figure 3.

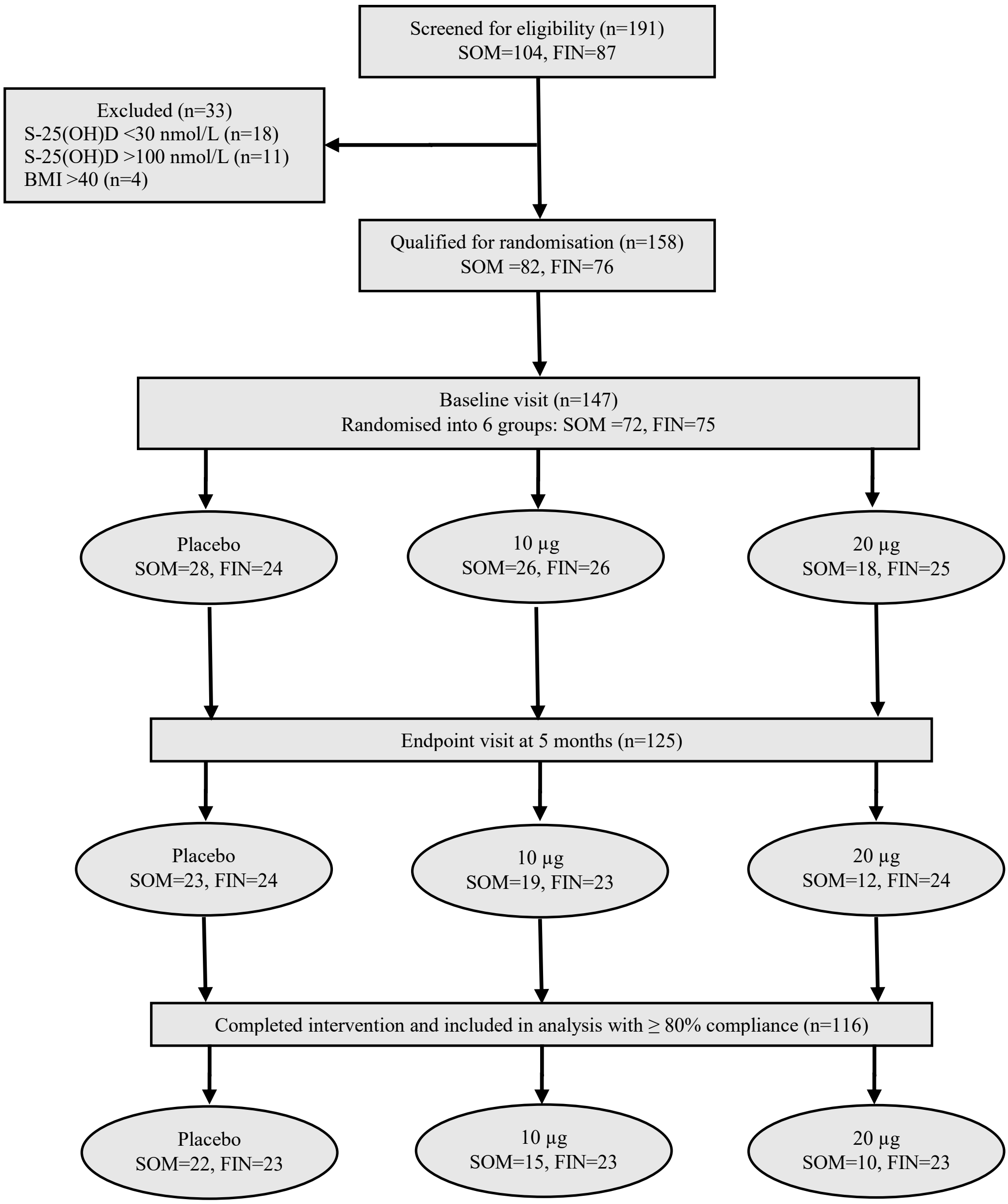

Figure 3. *Consolidated Standards of Reporting Trials (CONSORT) diagram. Details of the recruitment, randomization, and distribution of the participants in the Marwo-D Study.*
SOM, women of Somali origin; FIN, women of Finnish descent; S-25(OH)D, serum 25-hydroxyvitamin D

4.1.4 Ethical considerations

The studies were all approved by the Coordinating Ethics Committee of the Helsinki and Uusimaa Hospital District and were conducted according to the guidelines laid down in the Declaration of Helsinki. Written informed consent was obtained from all subjects. The consent form and the participant information sheet in Study III were provided in Somali and Finnish languages. The study was registered as a clinical trial on ClinicalTrials.gov (www.ClinicalTrials.gov; NCT02212223).

4.2 Measurements

Both the Maamu Study and the Health 2011 comprised questionnaires, interviews, and health examinations (including serum measurements) (Castaneda *et al.* 2012, Lundqvist & Mäki-Opas 2016). The questions on socio-demographic factors and health behaviours in both studies were similar. Dietary questions were asked during the interview in the Maamu Study. The Marwo-D intervention study included questionnaires (either delivered via interview or self-administered), a food frequency questionnaire (FFQ), and serum measurements. The main measurements employed in this thesis are presented in the next sub-sections.

4.2.1 Background variables; socio-demographic and health behaviour factors

In the Maamu Study and the Health 2011 Survey, information on age, sex, place of residence, and country of origin (for immigrants) was obtained from the sampling frame (Castaneda *et al.* 2012, Lundqvist & Mäki-Opas 2016). Information on age was collected through a detailed questionnaire in the Marwo-D intervention study. Other socio-demographic data were obtained during the interview in the Maamu Study and the Health 2011. Information on health behaviour was collected either during the interview (Maamu Study and Health 2011) or through the self-administered health questionnaire (Health 2011). The assessment for alcohol consumption was based on the Alcohol Use Disorders Identification Test (AUDIT) scores for men and women (Aalto *et al.* 2006, Tuunanen *et al.* 2007). Use of vitamin D supplements was examined during the interview in the Maamu Study, as a part of the FFQ in the Health 2011 and through a detailed questionnaire in the Marwo-D intervention study. BMI was calculated based on the height and weight (i.e. weight (kg)/ height (m^2)) measured during the health examination (Maamu Study and Health 2011) and at screening (Marwo-D intervention study). The options for the questions asked and categorization of background variables used in the three studies are presented in Table 9.

Table 9. *Summary of background variables: socio-demographic and health behaviour factors in Studies I-III.*

Background variables	**Study I Options and categories**	**Study II Options and categories**	**Study III Options and categories**
Participants' origin	Russian; Somali; Kurdish	Russian; Somali; Kurdish; Finnish	Somali; Finnish
Sex	Men; women	Men; women	Women
Age	18-29; 30-44; 45-64	18-29; 30-44; 45-64	21-64 (continuous)
Place of residence	(1) Metropolitan area: Helsinki, Espoo and Vantaa (2) Other municipalities: Turku, Tampere and Vaasa	NA	NA
Years lived in Finland	≤5; 6-14; ≥ 15 years	NA	NA
Marital status	(1) Married/partnership/cohabitation (2) Other: divorced or living apart, widowed or unmarried	NA	NA
Household size	1 person; 2-4 persons; > 4 persons	NA	NA
Educational status	Basic education (1) No basic education (2) Basic education or equivalent: either primary school or the equivalent / part of primary school or primary school and secondary school or equivalent / part of junior high school (3) High school or equivalent: high school or part of high school or an equivalent school	Education (1) Less than high school (2) High school	NA
Smoking status	NA	Smoking daily (1) No: occasionally and not at all (2) Yes: daily	NA
Alcohol consumption		Excess alcohol consumption: (1) No = AUDIT <6 points for men and	

	NA	<5 points for women (2) Yes = AUDIT ≥6 points for men and ≥5 points for women	NA
Physical activity	NA	(1) Inactive/less active: Inactive = mainly non-strenuous activities (reading and watching TV) Less active = moderately strenuous activities (walking, biking or light gardening) (2) Highly active: strenuous activities (fitness training or competitive sports several hours a week)	NA
Use of vitamin D supplements	NA	(1) No (2) Yes	NA
BMI	NA	(1) Non-obese (<30 kg/m2) (2) Obese (≥30 kg/m2).	BMI (continuous)
Season of blood sampling	NA	(1) Summer (April – September) (2) Winter (October – March	NA

NA: Not applicable

4.2.2 Dietary assessment

Dietary questions during interview (I and II)

In the Maamu Study, the health interview included extensive questions on food habits. The dietary questions were designed to measure consumption frequencies (not amounts) and eating habits (Castaneda *et al.* 2012). The participants were asked about their use of basic Finnish food items such as fat spread on bread, cooking fat, cheese, rye bread, fresh vegetables, fruit and berries, fish, and fluid dairy products. In Study I, four food variables (rye bread, fresh vegetables, fruits and berries, and fish) were selected as indicators of healthy food consumption. In Study II, consumption of the major dietary sources of vitamin D was examined based on three selected food variables (fat spread, fish, and fluid milk). The questions asked to assess the consumption of each food item are presented in Table 10.

Food frequency questionnaire (III)

In the Marwo-D intervention study, data on habitual dietary vitamin D intake were collected based on a validated, semi-quantitative, interview-administered food frequency questionnaire (Itkonen *et al.* 2016a). The FFQ was only validated in Finnish women (Caucasians), but piloted in a small Somali population (n=5) before its administration in the study. The FFQ, which aimed to estimate average dietary vitamin D intake during the previous month, was administered at the baseline and endpoint of the intervention. The FFQ included nine food groups, covering altogether 46 food items, which are considered important sources of vitamin D. The vitamin D intake was assessed with closed questions on consumption frequencies (daily, weekly, monthly, less often or not at all) and portion sizes (e.g. 1 glass or 1 piece). Open questions were utilized with respect to use of fat (e.g. spread on bread, in cooking and baking). In the FFQ, information on brand name of food products was asked from the participants with the aid of a picture booklet of vitamin D-fortified products. Pictures showing portion sizes were also used when needed. The dietary vitamin D intakes (from vitamin D-fortified fluid milk products and fat spreads, fish, and other sources) were calculated using data from the Finnish national food composition database Fineli®, which was developed and is continuously updated by the Finnish Institute for Health and Welfare (www.fineli.fi). In addition, vitamin D content of each vitamin D-fortified product was available on the food labels provided by the manufacturers.

Table 10. *Summary of dietary assessment in Studies I-III.*

Study and outcome measured	Data collection method	Selected food items	Questions asked	Options and categories
I Healthy food consumption	Dietary questions during interview	Rye bread	How many slices of rye bread do you normally eat in a day?	(1) 0 (2) ≥ 1 slice
		Fresh vegetables	How often have you eaten vegetables and root vegetables (except potatoes) during the last week (7 days) as such, in grated form, or in fresh salads?	(3) Not at all (4) 1-2 days per week (5) 3-5 days per week (6) 6-7 days per week
		Fruits and berries	How often have you eaten fruits and berries during the last week (7 days)?	(1) Not at all (2) 1-2 days per week (3) 3-5 days per week (4) 6-7 days per week
II Consumption of major dietary sources of vitamin D		Fish	How often have you eaten fish or fish dishes during the last month?	Study I (1) Not at all (2) 1 time per week or rarely (1-2 times per month or once per week) (3) ≥ 2 times per week (2 times per week or 3 or more times per week) Study II (1) < 2 times per week (2) ≥ 2 times per week
		Vitamin D-fortified fat spread	What type of fat spread do you use mostly on bread?	(1) No: non-use (2) Yes: use either <65% fat or ≥65% fat spreads
		Vitamin D-fortified fluid milk	How often have you consumed fluid milk products, such as milk, sour milk, or yoghurt, during the previous month?	(1) < daily: not at all, 1-2 times per month, once per week, 2-3 times per week and 4-6 times per week (2) Daily or several times per day

Table 10 continues.

Study and outcome measured	Data collection method	Selected food items	Questions asked	Options and categories
III Habitual dietary vitamin D intake	Interviewed FFQ*	(1) Vitamin D-fortified fluid milk products (2) Vitamin D-fortified fat spreads (3) Fish (4) Other sources (milk-based foods, main courses, mushrooms, vitamin D-fortified cheese, bread, juice and mineral water)	Consumption frequency during the previous month	Consumption frequency during the previous month

*Based on a validated, semi-quantitative, interview-administered FFQ (Itkonen *et al.* 2016a)

4.2.3 Laboratory measurements (II and III)

In this thesis, S-25(OH)D concentrations were measured as a biomarker for the assessment of vitamin D status. In all studies, fasting blood samples were collected and serum was separated and stored at -70°C until analysis (Lundqvist & Mäki-Opas 2016, Skogberg *et al.* 2016). The minimum average fasting period in both the Maamu Study and the Health 2011 (Study II) was 8 hours (Skogberg *et al.* 2016). Fasting blood samples in the Marwo-D intervention study (Study III) were drawn between 6:45 a.m. and 12:30 p.m. Also determined in Study III in relation to bone health were S-PTH, serum calcium (S-Ca), serum albumin, and phosphate (S-Pi) concentrations. Table 11 shows the summary of measurements for the biomarkers used in both Studies II and III.

The total S-25(OH)D concentrations from both the Maamu Study and the Health 2011 were standardized according to the VDSP by means of a certified LC-MS/MS at University College Cork, Ireland (Cashman *et al.* 2016, Jääskeläinen *et al.* 2017). The quality and accuracy of S-25(OH)D analysis by the LC-MS/MS in the Cork Centre for Vitamin D and Nutrition Research laboratory is guaranteed on an ongoing basis by participation in the DEQAS (Charing Cross Hospital) (Cashman *et al.* 2013). The LC-MS/MS method used is certified under the Centers for Disease Control and Prevention Vitamin D Standardization Certification Program (http://www.cdc.gov/labstandards/pdf/hs/CDC_Certified_Vitamin_D_Procedures.pdf). The VDSP ensures measurement accuracy and more valid comparison of S-25(OH)D data across studies and time (Sempos *et al.* 2012). The VDSP protocol is described in detail elsewhere (Binkley & Sempos 2014, Cashman *et al.* 2016). The total S-25(OH)D concentrations in the Marwo-D intervention study were assessed from the serum samples by the Cork Centre for Vitamin D and Nutrition Research at University College Cork, Ireland, using LC-MS/MS, which is the central analytical platform for the ODIN project.

In both Studies II and III, vitamin D status was defined according to the IOM S-25(OH)D thresholds (Ross *et al.* 2011), which are adopted in both the Nordic and Finnish Nutrition Recommendations (National Nutrition Council 2014, Nordic Council of Ministers 2014). S-25(OH)D >30 nmol/L was defined as deficient; S-25(OH)D 30 - <50 nmol/L as insufficient; S-25(OH)D ≥ 50 nmol/L as sufficient. In Study II, season of blood sampling was classified as summer (April – September) and winter (October – March).

Table 11. *Summary of laboratory measurements in Studies II and III.*

Study	Variable	Sampling period	Method (device)	Laboratory	CV% inter-assay and intra-assay
II	Serum 25-hydroxyvitamin D	Maamu Study: December 2010 - April 2012	Chemiluminescent immunoassay (Architect ci8200)*	THL	
		Health 2011: August - December 2011	Chemiluminescent immunoassay (Architect ci8200)*	THL	
			LC-MS/MS (VDSP)[1]	UCC	Maamu samples <5 Health 2011 <5
III	Serum 25-hydroxyvitamin D	Screening (October/November 2014)	LC-MS/MS[2]	UCC	<5, <6
	Serum parathyroid hormone	Baseline (December 2014)	Immunoluminescence (Immulite1000)**	UH	<8.0, <5.5
	Serum calcium[3]	Midpoint (February/March 2015)	Photometric (Konelab20)***	UH	<4.6, <4.6
	Serum albumin	Endpoint (April/May 2015)	Photometric (Konelab20)***	UH	<4.6, <4.6
	Serum phosphate		Photometric (Konelab20)***	UH	<4.6, <4.6

LC-MS/MS, liquid chromatography-tandem mass spectrometry; VDSP, Vitamin D Standardization Program
THL, Finnish Institute for Health and Welfare
UCC, Cork Centre for Vitamin D and Nutrition Research, University College Cork, Ireland
UH, Department of Food and Environmental Sciences, University of Helsinki, Finland
[1]Total S-25(OH)D concentrations from Maamu Study and Health 2011 were standardized according to the VDSP
[2]Measures S-25(OH)D_2 and S-25(OH)D_3 separately; total S-25(OH)D concentrations were calculated as the sum of the two values
[3]S-Ca results were used as albumin-corrected (S-Ca + 0.02 x (41.3 - S-Alb)), 41.3 = average albumin
*Abbott Laboratories, Abbott Park, IL, USA; **Siemens Healthcare Diagnostics, Malvern, PA, USA; ***Thermo Clinical Labsystems, Espoo, Finland

4.3 Statistical analyses

The statistical methods used in this thesis included descriptive statistics, non-parametric statistics, t-test, analysis of variance (ANOVA), repeated-measures analysis of covariance (ANCOVA), and linear and logistic regression models. In Studies I and II, the analyses involved the use of inverse probability weights (IPWs) (Robins *et al.* 1994, Härkänen *et al.* 2014), based on register information on age, sex, study group, study location, and marital status, in order to reduce bias due to non-response and different sampling probabilities. Finite population correction was also applied in the analyses of both studies because of a significant proportion of the total population included in the sample (Lehtonen & Pahkinen 2004). The results are presented as weighted prevalence and odds ratios (ORs) with 95% confidence intervals (CIs) (Studies I and II), weighted means with their 95% CIs (Study II), and mean values with standard deviations (SDs) or standard errors (Study III). The results of all analyses in the three studies were considered statistically significant at $p<0.05$. The statistical analyses were performed using the Statistical Analysis System for Windows, version 9.4 (SAS Institute Inc., Cary, NC, USA) in Studies I and II and IBM Statistical Package for the Social Sciences Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA) in Study III. A summary of the major statistical analyses of this thesis is presented in Table 12.

Study I

Data were analysed separately for each immigrant group and differences in socio-demographic characteristics and healthy food consumption between males and females were examined using Chi-square test. Associations between socio-demographic factors and food consumption were analysed using logistic regression models. The variables included in both unadjusted and adjusted models are presented in Table 12. Based on preliminary analyses, years lived in Finland and marital status were not associated with the variables of interest. Thus, they were not included in the final models. Due to uncommon daily consumption of fresh vegetables and fruits and berries observed among Somali participants, different cut-offs (at least 3 days/week) were adopted for the Somalis regarding fresh vegetables and fruits and berries.

Study II

Comparisons between the immigrant groups and the Finnish reference group regarding participant's characteristics and vitamin D status were only analysed for participants aged 30-64 years because of the limited available data on S-25(OH)D concentration for younger (18-29 years) Finnish participants. All other analyses carried out among the immigrant groups included individuals aged 18-64 years. The differences between groups were examined using linear (continuous variables) and logistic (categorical variables) regression. The potential determinants of vitamin D deficiency (S-25(OH)D <30 nmol/L) and insufficiency (<50 nmol/L) were analysed with logistic models. The compositions of the multivariable models employed are shown in Table 12.

Study III

Power of the study (90%, $\alpha = 0.5$) was calculated based on the S-25(OH)D concentrations in order to detect a minimum 10 nmol/L increase in S-25(OH)D between groups within an ethnic group. With reference to the distribution of wintertime S-25(OH)D data in a previous study of white adult Finnish women (Itkonen *et al.* 2016b), it was assumed that the distribution of wintertime S-25(OH)D would be similar for non-white adult Finnish women of similar numbers per group. It was calculated that 34 subjects should be recruited per group, but the number was increased to 40 for each dose group (placebo, 10 µg/d, and 20 µg/d in each ethnic group) to cover possible dropouts. The intention was to enroll a total of 240 women (120 in each ethnic group) but the targeted sample size was not reached because of the seasonal timeframe (i.e. wintertime) of the study, which did not allow extension of the recruitment period for more participants.

The normal distribution of variables was tested with Kolmogorov-Smirnov test. Differences in normally distributed variables in intervention groups within both ethnic groups were evaluated with ANOVA and non-parametric test (Kruskal-Wallis) was used to assess differences in non-normally distributed variables. Variables between the two ethnic groups were compared with t-test (normally distributed variables) and non-parametric Mann-Whitney U test (non-normally distributed variables). Differences in vitamin D intakes (from diet and/or supplement) between supplement users and non-users as well as between the two groups of women were examined using Mann-Whitney U test. The effects of supplementation on S-25(OH)D, S-PTH, S-Ca, and S-Pi in the two ethnic groups were assessed with repeated-measures ANCOVA (Table 12). The baseline S-25(OH)D, S-PTH, S-Ca, or S-Pi concentration was used as a covariate in ANCOVA. The comparisons between intervention groups were carried out with contrasts.

In the final analysis on the effects of intervention, only the participants who completed the intervention and had $\geq$ 80% compliance rate with study supplementation in each group were included. However, three participants were excluded from the analysis for the following reasons: pregnancy (n=1), kidney dysfunction (n=1), and sunburn (n=1). Altogether, data from 116 participants were analysed. Additional analyses were performed for the evaluation of vitamin D status in the two ethnic groups with regard to S-25(OH)D concentrations in all screened subjects (n=191) and vitamin D intake from the diet and supplements in all randomized subjects (n=147).

Table 12. *Summary of the major statistical analyses of the thesis.*

Study	Main variables	Statistical methods	Models
I	**Outcome:** Consumption of healthy foods: rye bread vegetables, fruits and berries, and fish food **Determinants:** Socio-demographic factors: sex, age, basic education, place of residence, and household size	Logistic regression; data analysed separately for each immigrant group	**Unadjusted model:** Each food (rye bread, vegetables, fruits and berries, fish food) and each socio-demographic (sex, age, basic education, place of residence, and household size) variables of interest separately **Adjusted model:** Unadjusted model + all other socio-demographic variables
II	**Outcomes:** Total S-25(OH)D Vitamin D deficiency (S-25(OH)D <30 nmol/L) Vitamin D insufficiency (<50 nmol/L) Consumption of dietary sources of vitamin D **Determinants:** Background variables: sex, age, immigrant group, education, BMI, daily smoking, alcohol consumption, physical activity, use of vitamin D supplements, season of blood sampling Dietary variables: consumption of vitamin D-fortified fat spread, fish consumption, and vitamin D-fortified fluid dairy products consumption	Logistic regression; data analysed only among immigrant groups T tests; data analysed between immigrant groups and the general Finnish population as well as among the immigrant groups	**Model 1:** Age, season of blood sampling and immigrant group + a variable of interest (sex, education, BMI, daily smoking, alcohol consumption, physical activity, use of vitamin D supplements, consumption vitamin D-fortified fat spread, fish consumption, and vitamin D-fortified fluid dairy products consumption) and vitamin D status (S-25(OH)D <30 or <50 nmol/L) **Model 2:** Model 1 + all other variables

Table 12 continues.

Study	Main variables	Statistical methods	Models
III	**Outcomes:** Total S-25(OH)D S-25(OH)D cut-offs Effect of vitamin D_3 supplementation on S-25(OH)D Total daily vitamin D intake Daily vitamin D intake from dietary sources **Confounders:** Intervention groups: Placebo and 10 and 20 µg/d vitamin D_3 Intervention visits: Baseline, midpoint, and endpoint Supplement use Vitamin D-rich foods: Vitamin D-fortified fluid milk products and fat spreads, fish, and other sources	Repeated-measures analysis of covariance (ANCOVA); data stratified by ethnicity groups Mann-Whitney U test; data analysed according to supplement use and groups of women	ANCOVA model: S-25(OH)D at the three visits, the three intervention groups, and baseline S-25(OH)D concentration as a covariate

5 RESULTS

5.1 Characteristics of the participants

Study I

Descriptive statistics of the 1372 participants in Study I are presented in Table 13. The majority of the Russian Somali participants were women. Participation rate was higher among Kurdish men than Kurdish women. Participants of Russian origin were older and had higher educational status than the other immigrant groups. The study was more characterized by participants who lived in the Helsinki metropolitan area and those who were married, had registered partners, or were cohabiting. Participants of Somali background had the largest household size.

Table 13. *Characteristics of the participants in Study I*[1].

	Russian (n=527)		Somali (n=337)		Kurdish (n=508)	
	n	%	n	%	n	%
Sex						
Men	188	36	156	46	291	57
Women	339	64	181	54	271	43
Age (years)						
18-29	153	29	142	42	176	35
30-44	164	31	128	38	224	44
45-64	210	40	67	20	108	21
Education						
None	-	-	78	23	58	11
Basic school/equivalent	104	20	160	48	233	46
High school/equivalent	423	80	96	29	216	43
Place of residence						
Metropolitan area	418	79	292	87	278	55
Other municipalities	109	21	45	13	230	45
Years in Finland						
<=5	110	21	74	22	104	21
6-14	220	42	134	40	271	53
>=15	197	37	126	38	132	26
Marital status						
Married/Partnership/Cohabitation	227	43	116	35	177	35
Other	300	57	217	65	331	65
Household size						
1 person	121	23	59	17	105	21
2-4 persons	381	72	121	36	277	54
> 4 persons	25	5	157	47	126	25

[1]Weighted n and prevalence (%)

Basic education: No = participant had not received formal school education; Basic education or equivalent = attended either primary school or the equivalent / part of primary school or primary school and secondary school or equivalent / part of junior high school; High school or equivalent = attended high school or part of high school or an equivalent school.

Place of residence: Metropolitan area = Helsinki, Espoo, and Vantaa; Other municipalities = Turku, Tampere, and Vaasa.

Marital status category "Other" = divorced or living apart, widowed, or unmarried.

Missing information: For Somalis: education (n=2), years in Finland (n=3), marital status (n=4); for Kurds: education (n=1), years in Finland (n=1).

Study II

Table 14 shows the characteristics of the 888 immigrant and 798 Finnish participants, aged 30-64 years in Study II. Somali and Kurdish participants were younger than Russians and the general Finnish population. Obesity was observed among 49% of Somali women and one-third of Kurdish women, while only 5% of Somali men were obese. Prevalence of obesity did not differ between Kurdish men and Finnish men. Similar low prevalence of obesity and higher proportion of physical activity were found in Russian and Finnish participants. Participants of Somali (18%) and Kurdish (21%) origin had lower proportions of being highly physically active than the Finnish reference group. The proportion of vitamin D supplements use was lower in the immigrant groups, especially among women, than in the Finnish participants. Blood samples of the Russian and Kurdish participants, which were mostly collected during the winter season, differed from those of Finns. The blood samplings of Somalis were almost equally distributed between the summer and winter seasons and were similar to those of Finns.

Table 14. *Characteristics of the participants (aged 30-64 years) in Study II: the immigrant groups (Maamu Study) and the general Finnish population (Health 2011)*[1].

	Men				Women			
	Russian (n=111) n (%)	**Somali (n=79) n (%)**	**Kurdish (n=176) n (%)**	**Finnish (n=352) n (%)**	**Russian (n=217) n (%)**	**Somali (n=142) n (%)**	**Kurdish (n=163) n (%)**	**Finnish (n=446) n (%)**
Age (years)								
30-44	58 (53)	51 (68)	111 (66)	115 (42)	85 (39)	88 (66)	111 (69)	159 (42)
45-64	53 (47)	28 (32)	65 (34)	237 (58)	132 (62)	54 (34)	52 (31)	287 (58)
p value	0.076	<0.001	<0.001		0.444	<0.001	<0.001	
High school education[2]	84 (82)	35 (57)	75 (46)	199 (54)	177 (83)	17 (14)	64 (41)	298 (66)
p value	<0.001	0.764	0.093		<0.001	<0.001	<0.001	
Obesity	18 (18)	7 (5)	35 (20)	59 (19)	50 (23)	67 (49)	49 (30)	95 (22)
p value	0.851	<0.001	0.672		0.826	<0.001	0.003	
Daily smokers	32 (31)	7 (4)	42 (26)	58 (21)	20 (9)	0 (0)	7 (4)	70 (17)
p value	0.082	<0.001	0.318		0.011	NA	<0.001	
Excess alcohol consumers[3]	15 (13)	0 (0)	6 (4)	102 (29)	12 (8)	0 (0)	2 (1)	107 (25)
p value	<0.001	NA	<0.001		<0.001	NA	NA	
High physically active persons[4]	27 (24)	15 (18)	38 (24)	97 (31)	50 (23)	18 (18)	27 (17)	106 (25)
p value	0.157	0.012	0.044		0.664	0.081	0.013	
Vitamin D supplement-users	7 (6)	4 (7)	15 (9)	47 (14)	23 (10)	9 (12)	23 (15)	106 (24)
p value	0.008	0.059	0.057		<0.001	0.005	0.015	
Season of blood sampling								
Summer (April – September)	42 (38)	35 (50)	56 (32)	178 (51)	80 (36)	65 (49)	57 (33)	222 (51)
Winter (October – March	69 (62)	44 (50)	120 (69)	174 (49)	137 (64)	77 (52)	106 (67)	224 (49)
p value	0.014	0.959	<0.001		<0.001	0.654	<0.001	

[1]Crude n and weighted prevalence (%). *P* values from T tests = difference between immigrant groups and the general Finnish population, bolded *p* values (<0.05) represent significant differences.

[2]Education (in any country): Less than high school = had not received formal school education or attended either primary school or the equivalent/part of primary school or primary school and secondary school or equivalent/part of junior high school; High school or equivalent = completed high school or part of high school or an equivalent school (none of the Finnish and Russian men and women reported no educational attainment).
[3]Excess alcohol consumption: No = AUDIT <6 points for men and <5 points for women; Yes = AUDIT ≥6 points for men and ≥5 points for women (None of the Somali men and women reported excess alcohol consumption).
[4]Physically activity: inactive = mainly non-strenuous activities such as reading and watching TV; moderately active = moderately strenuous activities such as walking, biking, or light gardening; highly active = strenuous activities such as fitness training or competitive sports several hours a week.
NA = not applicable (too few observations for statistical analysis in the cell "yes" for smoking and alcohol consumption).
Missing information: For Russians: education (n=5), smoking (n=4), alcohol consumption (n=17), physical activity (n=4), use of vitamin D supplements (n=13)
For Somalis: education (n=17), smoking (n=22), alcohol consumption (n=50), physical activity (n=50), use of vitamin D supplements (n=53)
For Kurds: education (n=10), BMI (n=4), smoking (n=9), alcohol consumption (n=25), physical activity (n=11), use of vitamin D supplements (n=28)
For Finns: education (n=10), BMI (n=2), smoking (n=11), alcohol consumption (n=17), physical activity (n=14), use of vitamin D supplements (n=19)

Study III

Altogether 147 participants; Somali (East African; n=72) and Finnish (Caucasian; n=75) women, were randomized in the study. Mean compliance with supplementation was 89% for Somali women (n=54) and 98% (n=71) for Finnish women. Table 15 presents the characteristics of the 116 participants included in the final analyses. No differences were found with regard to any background data among the intervention groups within each ethnic group. However, Somali women differed from Finnish women in all characteristics, except for S-Pi concentrations.

Table 15. *Baseline characteristics of the participants (n=116) in Study III; stratified by ethnicity.*

	Somali women n=47	**Finnish women n=69**	***P* value**
Age (years)†	41.2 (8.0)	32.7 (8.0)	**<0.001**
Height (cm)	163.1 (5.3)	166.2 (6.2)	**0.006**
Weight (kg)†	78.2 (13.3)	65.7 (12.0)	**<0.001**
BMI (kg/m^2)†	29.4 (4.8)	23.8 (4.0)	**<0.001**
Dietary vitamin D intake (µg/d)†	11.3 (5.1)	8.4 (4.1)	**0.002**
Vitamin D intake from personal supplement (µg/d)†	11.2 (10.1)	5.7 (9.3)	**<0.001**
Total vitamin D intake from diet and personal supplement (µg/d)†	22.5 (12.6)	14.1 (10.5)	**<0.001**
Baseline serum 25(OH)D (nmol/L)	52.2 (14.0)	60.5 (16.6)	**0.006**
Baseline serum PTH (pg/ml)†*	45.2 (24.7)	34.1 (17.0)	**0.021**
Baseline albumin-corrected calcium (mmol/L)	2.54 (0.09)	2.49 (0.09)	**0.002**
Baseline serum phosphate (mmol/L)	1.27 (0.14)	1.30 (0.17)	0.291

Values are mean (SD), vitamin D intakes calculated from FFQ (mean of baseline and endpoint). BMI = body mass index. 25(OH)D = 25-hydroxyvitamin D
Significant differences between Somali and Finnish women are presented in bold. *P* values <0.05 from T-tests, except † non-parametric tests
* n=112 for serum PTH analysis

5.2 Consumption of healthy and vitamin D-rich foods (I and II)

In both Studies I (n=1372) and II (n=1185), ethnic differences in the consumption of healthy foods (rye bread, vegetables, fruits and berries, and fish) and vitamin D-rich foods were observed among immigrant participants. Rye bread was consumed daily by a higher proportion of Russian and Somali participants than Kurdish participants (Table 16). Fresh vegetables were more often consumed by participants of Russian and Kurdish origin than by Somali participants. Similarly, consumption of fruits and berries was more frequent among Kurds and Russians than among Somalis. However, 85% of Somali participants consumed fresh vegetables, and 78% consumed fruits and berries on 1-2 days a week. Fish was more frequently consumed by Russian (43% in both studies) and Somali (37% in Study I; 38% in Study II) participants than Kurdish participants (19% in Study I; 17% in Study II). Vitamin D-fortified fat spread was frequently used by a higher proportion of Somalis than Russian and Kurdish participants. More than half of participants with Russian and Kurdish background consumed vitamin D-fortified fluid dairy products daily, compared with only one-third of Somali participants.

Table 16. *Consumption of healthy and vitamin D-rich foods by immigrant groups (Studies I and II)[1].*

	Russian (n=527)		Somali (n=337)		Kurdish (n=508)	
	n	**%**	**n**	**%**	**n**	**%**
Rye bread daily[2]						
No	108	21	90	27	216	43
Yes	417	79	243	73	291	57
Vegetables per week[2]						
Not at all	18	3	37	11	26	5
1-2 days/week	64	12	283	85	127	25
3-5 days/week	129	25	11	3	133	26
6-7 days/week	316	60	4	1	222	44
Fruits and berries per week[2]						
Not at all	12	2	51	15	13	2
1-2 days/week	81	16	263	78	105	21
3-5 days/week	118	22	20	6	72	14
6-7 days/week	315	60	3	1	318	63
Fish per week						
Study I[2]						
Not at all	19	4	35	10	78	15
1 time per week/rarely	282	53	178	53	333	66
≥ 2 times per week	226	43	124	37	97	19
Study II[3]						
< 2 times per week	240	57	195	62	377	83
≥ 2 times per week	190	43	99	38	84	17
Fat spread[3]						
No	116	27	29	9	178	40
Yes	310	73	265	91	283	60
Fluid dairy products[3]						
<Daily	179	43	159	64	206	44
Daily or several times a day	251	57	133	36	255	56

[1]Weighted prevalence.

[2]Weighted n.

[3]Crude n (Russians n=430, Somalis n=294, Kurds n=461)

Rye bread daily: Yes = ate ≥ 1 slice.

Study I: Fish per week: ate fish 1 time per week/rarely (1-2 times per month or once per week); ate fish ≥ 2 times per week (i.e. 2 times per week or 3 or more times per week).

Missing information: For Russians: rye bread (n=2), fruits and berries (n=1), fat spread (n=4); for Somalis: rye bread (n=4), vegetables (n=2), fluid dairy products (n=2); for Kurds: rye bread (n=1)

5.3 Associations between healthy food consumption and socio-demographic factors (I)

Table 17 shows the multivariate associations between healthy food consumption and socio-demographic factors for each ethnic group of immigrants. Among persons of Russian origin, differences in the consumption of healthy foods existed with regard to sex, age, and household size (Table 17). Russian women were more likely than men to consume fruits and berries; the oldest age group was more likely to eat fresh vegetables and fruits and berries than the youngest participants; and those with a larger household size were more likely to consume rye bread.

Differences in the consumption of healthy foods were observed in relation to all socio-demographic factors among Kurdish participants (Table 17). Vegetables and rye bread were more likely to be consumed by Kurdish women than men. Daily consumption of fruits and berries were more likely to occur nearly twice among the oldest age group than among the youngest one. Fresh vegetables were more likely to be eaten daily by Kurdish participants with the highest educational level, but less likely to be consumed by those living in the metropolitan area and those with a smaller household size. Kurdish persons living in the metropolitan area were more likely to consume fish frequently than those living in other municipalities.

Consumption of healthy foods among participants of Somali origin differed by age, education, and place of residence (Table 17). Fresh vegetables and fruits and berries were less likely to be consumed by Somalis in the older age groups (30-64 years). Fish was more likely to be consumed by 30–44-year-olds, while rye bread was more likely to be eaten by 30–64-year-olds than by younger participants. Somali participants with the highest educational level were more likely to consume fresh vegetables, whereas those living in the metropolitan area were less likely to consume both fresh vegetables and fruits and berries.

Table 17. *Associations between healthy food consumption and socio-demographic factors according to ethnic groups.*

	Russian (n=527)				Kurdish (n=508)				Somali (n=337)			
	Vegetables (6-7 days/ week)	**Fruits and berries (6-7 days/ week)**	**Fish (at least 2 times/week)**	**Rye bread (at least 1 slice/day)**	**Vegetables (6-7 days/ week)**	**Fruits and berries (6-7 days/ week)**	**Fish (at least 2 times/week)**	**Rye bread (at least 1 slice/day)**	**Vegetables (at least 3 days/week)***	**Fruits and berries (at least 3 days/week)***	**Fish (at least 2 times/week)**	**Rye bread (at least 1 slice/day)**
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
Sex												
Men	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Women	1.21 (0.79-1.86)	**1.87‡ (1.21-2.90)**	0.87 (0.57-1.33)	1.10 (0.66-1.83)	**1.62‡ (1.12-2.34)**	1.35 (0.94-1.95)	0.85 (0.55-1.33)	**3.22‡ (2.21-4.69)**	2.21 (0.79.-6.18)	1.06 (0.42-2.65)	0.75 (0.43-1.30)	0.61 (0.33-1.12)
Age (years)												
18-29	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30-44	1.28 (0.75-2.19)	1.16 (0.68-1.97)	0.90 (0.52-1.54)	1.25 (0.67-2.31)	0.96 (0.64-1.45)	1.28 (0.85-1.92)	0.90 (0.55-1.48)	1.00 (0.66-1.51)	**0.27‡ (0.09-0.82)**	**0.29‡ (0.10-0.79)**	**2.17‡ (1.20-3.93)**	**3.08‡ (1.64-5.76)**
45-64	**1.91‡ (1.14-3.19)**	**2.14‡ (1.27-3.59)**	1.43 (0.86-2.36)	1.50 (0.84-2.70)	1.48 (0.91-2.40)	**1.94‡ (1.17-3.20)**	1.30 (0.74-2.29)	1.59 (0.96-2.62)	**0.24‡ (0.07-0.79)**	0.51 (0.13-2.00)	1.14 (0.56-2.33)	**3.34‡ (1.46-7.65)**
Basic education												
No					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Basic school/ equivalent	1.00	1.00	1.00	1.00	1.14 (0.64-2.02)	1.01 (0.56-1.81)	1.53 (0.73-3.24)	0.99 (0.57-1.73)	1.33 (0.54-3.30)	2.07 (0.85-5.08)	1.21 (0.62-2.35)	1.29 (0.66-2.53)
High school/ equivalent	0.66 (0.39-1.13)	1.01 (0.60-1.71)	1.35 (0.82-2.24)	1.16 (0.64-2.11)	**1.85‡ (1.05-3.29)**	0.97 (0.54-1.73)	1.38 (0.64-2.96)	1.65 (0.93-2.91)	**5.35‡ (1.24-23.14)**	2.96 (0.84-10.49)	1.71 (0.79-3.71)	1.83 (0.74-4.51)
Place of residence												
Metropolitan area	0.91 (0.61-1.34)	0.88 (0.59-1.32)	1.13 (0.77-1.67)	1.16 (0.74-1.83)	**0.61‡ (0.43-0.86)**	0.96 (0.68-1.37)	**1.60‡ (1.04-2.45)**	1.13 (0.79-1.62)	**0.10‡ (0.03-0.32)**	**0.24‡ (0.11-0.53)**	0.80 (0.47-1.35)	1.30 (0.75-2.25)
Other municipalities	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Household size												
1 person	0.79 (0.29-2.10)	0.44 (0.16-1.18)	0.57 (0.21-1.59)	**0.01‡ (0.00-0.08)**	**0.44‡ (0.25-0.78)**	0.80 (0.46-1.37)	1.29 (0.66-2.53)	0.74 (0.43-1.28)	2.80 (0.58-13.37)	1.24 (0.27-5.75)	0.69 (0.32-1.48)	0.98 (0.40-2.42)
2-4 persons	1.53 (0.62-3.73)	1.09 (0.44-2.73)	1.14 (0.45-2.89)	**0.02‡ (0.00-0.12)**	**0.64‡ (0.43-0.97)**	1.35 (0.89-2.05)	1.21 (0.70-2.10)	0.68 (0.44-1.06)	1.85 (0.59-5.79)	2.03 (0.71-5.83)	0.95 (0.53-1.71)	0.66 (0.36-1.21)
> 4 persons	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Significant associations are presented in boldface. Odds ratios (ORs) and 95% confidence intervals (CIs) from logistic regression (adjusted model for all socio-demographic variables).

‡ Statistically significant adjusted results (*p* values <0.05).

Basic education: No = participant had not received formal school education; Basic education or equivalent = attended either primary school or the equivalent / part of primary school or primary school and secondary school or equivalent / part of junior high school; High school or equivalent = attended high school or part of high school or an equivalent school.

Place of residence: Metropolitan area = Helsinki, Espoo, and Vantaa; Other municipalities = Turku, Tampere, and Vaasa.

*Cut-offs (at least 3 days/week = 3-5 days or for 6-7 days) for the Somalis regarding fresh vegetables and fruits and berries.

Fish at least 2 times/week = ate fish 2 times per week or 3 or more times per week.

Rye bread daily at least 1 slice/day = ate ≥ 1 slice.

Missing information: For Russians: rye bread (n=2), fruits and berries (n=1); for Kurds: education (n=1), years in Finland (n=1), rye bread (n=1); for Somalis: education (n=2), years in Finland (n=3), marital status (n=4), rye bread (n=4), vegetables (n=2).

5.4 Vitamin D intake and sources (III)

Based on the calculation from the baseline FFQ consumption, the daily total vitamin D intake is presented according to supplement non-users and supplement users in Figure 4. The proportions of supplement use among Somali (n=72) and Finnish (n=75) women were 88% and 47%, respectively. Nevertheless, mean vitamin D intakes from supplements were similar among the voluntary vitamin D supplement users in both ethnic groups. Higher total mean vitamin D intake was found among participants using personal supplements than among non-users in both groups of women.

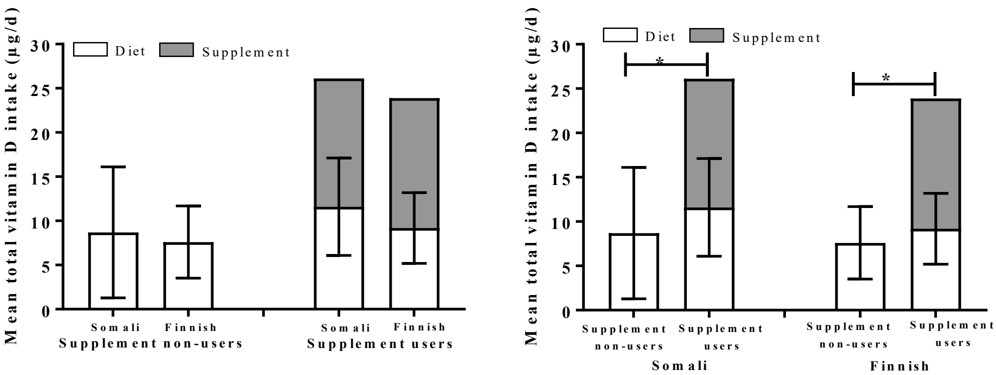

Figure 4. *Mean (SD) vitamin D intakes (µg/d) calculated from baseline FFQ.*
**P* values from Mann-Whitney U test (<0.001) for differences between groups of participants. Range from diet: 1.5-29.9 µg/d (Somali women); 1.1-18.6 µg/d (Finnish women). Range from supplement: 0.0-60.0 µg/d (Somali women); 0.0-57.5 µg/d (Finnish women). Range of total intake: 1.5-89.9 µg/d (Somali women); 1.1-68.2 µg/d (Finnish women). Diet Supplement.

Somali women had higher mean habitual vitamin D intakes from both diet (11.2 [SD=5.8] vs. 8.4 [SD=4.1] µg/d, *p*=0.003) and supplements (13.0 [SD=11.6] vs. 6.9 [SD=12.6] µg/d, *p*<0.001) than Finnish women. A higher proportion of participants who attained daily recommended vitamin D intake of 10 µg (National Nutrition Council 2014; Nordic Council of Ministers 2014) from diet and supplements was observed among Somali women (83%; n=60) than among Finnish women (55%; n=41) (*p*=0.003). The dietary sources contributing to the mean daily intake of vitamin D for both Somali and Finnish women are presented in Figure 5. Fortified fluid milk products were the major source of vitamin D for both groups of women, with higher intake among Somali women. The vitamin D intake from fortified fat spread and fish was similar in both groups.

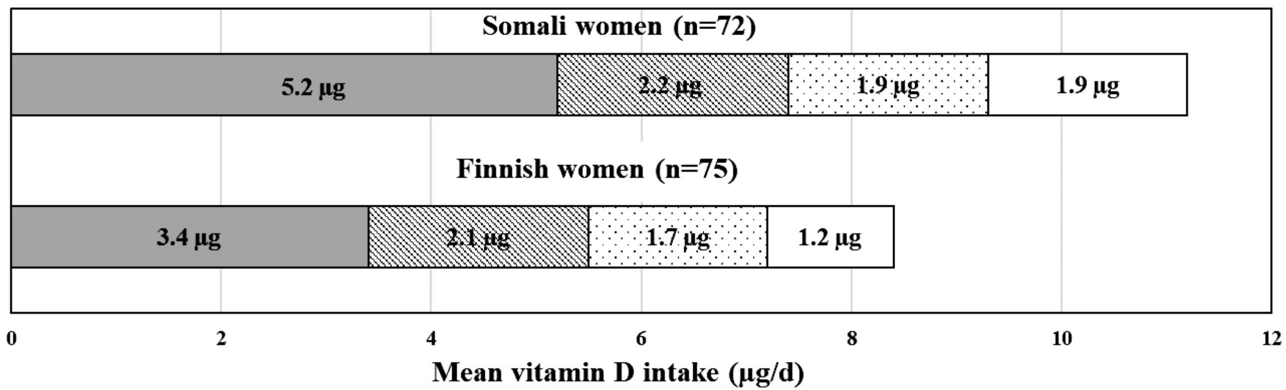

Figure 5. *Baseline daily vitamin D intake from dietary sources.*
Values are mean, vitamin D intakes calculated from baseline FFQ. Fortified fluid milk products; Fortified fat spreads; Fish; Others (milk-based foods, main courses, mushrooms, vitamin D-fortified cheese, bread, juice and mineral water)

5.5 Serum 25-hydroxyvitamin D concentrations and vitamin D status (II and III)

In Study II, lower mean [95% Cl] S-25(OH)D concentrations were found among Kurds (35 [34, 37] nmol/L) and Somalis (44 [41, 46] nmol/L) compared with Finns (64 [62, 66] nmol/L) (Figure 6). Russians had mean S-25(OH)D concentrations (64 [62, 66] nmol/L) that were similar to Finns. There were no differences in the mean S-25(OH)D concentrations between men and women in any of the study groups.

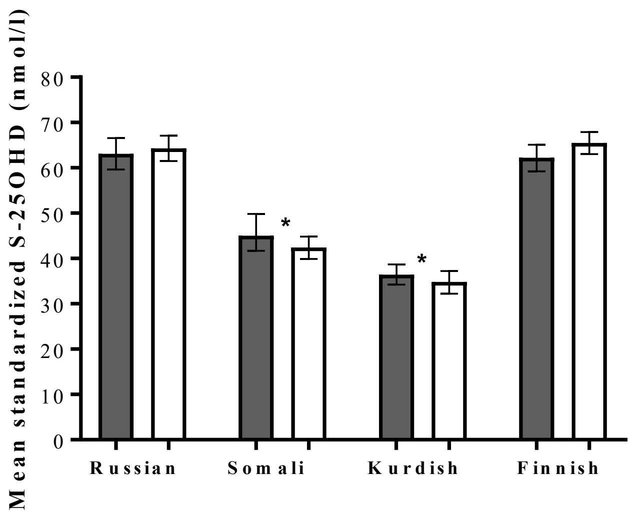

Figure 6. *Weighted mean and 95% confidence interval (95% CI) of standardized S-25-hydroxyvitamin D concentrations*

Adjusted for age and month of blood sampling. **P* values from T tests (**<0.001**) for mean standardized S-25(OH)D differences between immigrant groups and the general Finnish population.

Men Women. S-25(OH)D, serum 25-hydroxyvitamin D.

In Study III, higher baseline mean S-25(OH)D concentrations were observed among Finnish women (mean: 60.5 [SD=16.3] nmol/L) than among Somali women (mean: 51.5 [SD=15.4] nmol/L) (p=0.001), (data not shown). Vitamin D status of participants in both Studies II and III was examined according to the IOM thresholds for S-25(OH)D concentrations (Ross *et al.* 2011). The vitamin D status of the subjects in Studies II and III (screened subjects) is presented in Table 18. In Study II, the prevalence of vitamin D deficiency was higher among Somali and Kurdish participants than among Russians and Finns, while insufficient vitamin D status was higher in the three immigrant groups than in Finnish participants. In Study III, no vitamin D deficiency was found among Finnish women.

Table 18. *Distribution of vitamin D status (according to IOM S-25(OH)D cut-offs) in Studies II and III (frequencies and percentages).*

S-25(OH)D (nmol/L)	Vitamin D status	Study II[1]				Study III[2]	
		Russian (n=328)	Somali (n=221)	Kurdish (n=339)	Finnish (n=798)	Somali (n=104)	Finnish (n=87)
		n (%)	n (%)	n (%)	n (%)	n (%)	n[2] (%)
<30	Deficient	13 (4)	48 (24)	164 (49)	6 (1)	18 (17)	0 (0)
30 – 49.9	Insufficient	80 (24)	113 (52)	124 (36)	46 (6)	40 (39)	8 (9)
≥50	Sufficient	235 (72)	60 (24)	51 (15)	746 (93)	46 (44)	79 (91)

[1]Crude n, weighted prevalence (%), adjusted for age and month of blood sampling.
[2]Crude n and prevalence (%). Only women (at screening)

5.6 Determinants of vitamin D deficiency and insufficiency (II)

The evaluation of vitamin D status among only immigrants (aged 18-64 years) in Study II shows just 4% of Russian participants as deficient (S-25(OH)D <30 nmol/L), while the proportions were 30% and 51% for Somali and Kurdish participants, respectively. Due to the few observations of S-25(OH)D <30 nmol/L among Russians, the determinants of vitamin D deficiency are presented only for the Somali (n=102) and Kurdish (n=252) participants in Figure 7. In the final multivariable model, Kurdish participants (OR 1.97 [95% CI 1.31-2.96]) were at higher risk of vitamin D deficiency than Somalis (p<0.001). The independent determinants of vitamin D deficiency were obesity and daily smoking (p≤0.04, for both). Lower odds of vitamin D deficiency were associated with belonging to the oldest age group (45-64 years), being physically active, and using vitamin D supplements (p≤0.04, for all). Consumption of vitamin D-fortified fat spread and daily consumption of vitamin D-fortified fluid dairy products were also associated with reduced odds of vitamin D deficiency (p≤0.004, for both). No association was found between vitamin D deficiency and sex, education, alcohol consumption, or fish consumption (p≥0.05, for all).

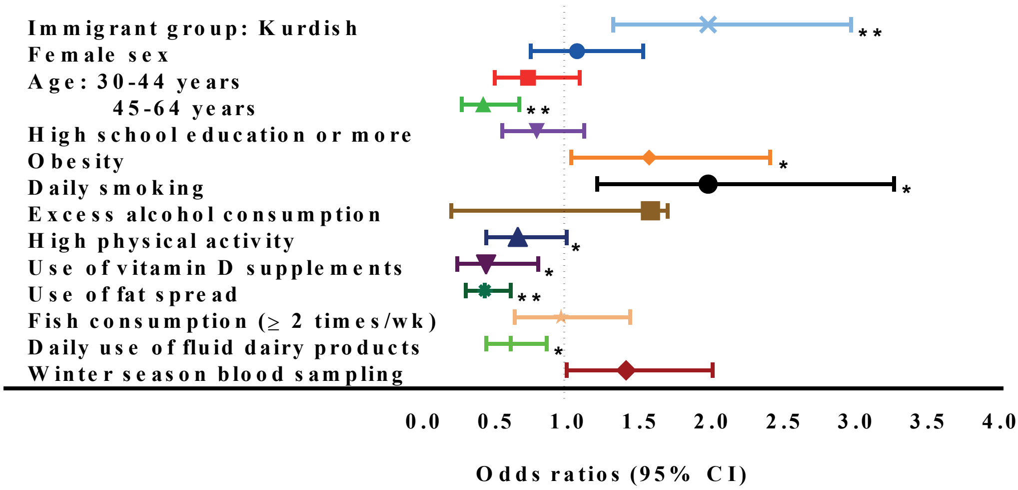

Figure 7. *Association of socio-demographic and health behaviour determinants and season of sampling with vitamin D deficiency (S-25(OH)D <30 nmol/L)*

Associations from logistic regression (adjusted model for all variables). ***P* values <0.001; **P* values <0.05. References: Somali; male; 18-29 years; < high school; < 30 kg/m2; no smoking; no alcohol; inactive/less active; no vitamin D supplements; summer season blood sampling; no fat spread; < 2 times/week fish; < daily fluid dairy products.

Regarding vitamin D insufficiency, 29% of Russians (n=128), 78% of Somalis (n=278), and 86% of Kurds (n=428) had S-25(OH)D below 50 nmol/L. The determinants of vitamin D insufficiency for the three immigrant groups are presented in Figure 8. In the final multivariable model, vitamin D insufficiency was less common in Russians (OR 0.12 [95% CI 0.08-0.20]) than in Somalis ($p<0.001$). The model showed daily smoking, excess alcohol consumption, and blood sampling in the winter season as the significant determinants of vitamin D insufficiency ($p\leq0.03$, for all). Lower odds of vitamin D insufficiency were associated with older age (45-64 years), physical activity, fish consumption according to the recommendations, and daily consumption of vitamin D-fortified fluid dairy products ($p\leq0.04$, for all). Sex, education, BMI, use of vitamin D supplements, and consumption of vitamin D-fortified fat spread were not associated with vitamin D insufficiency ($p\geq0.05$, for all).

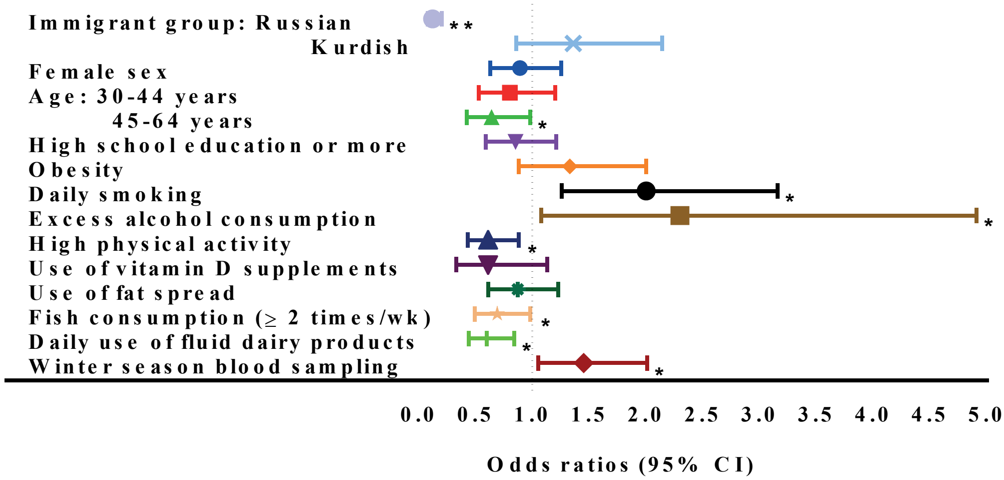

Figure 8. *Association of socio-demographic and health behaviour determinants and season of sampling with vitamin D insufficiency (S-25(OH)D <50 nmol/L)*

Associations from logistic regression (adjusted model for all variables). ***P* values <0.001; **P* values <0.05. References: Somali; male; 18-29 years; < high school; < 30 kg/m2; no smoking; no alcohol; inactive/less active; no vitamin D supplements; summer season blood sampling; no fat spread; < 2 times/week fish; < daily fluid dairy products.

5.7 Effect of vitamin D supplementation on S-25(OH)D, S-PTH, S-Ca, and S-Pi (III)

In Study III, significantly increased S-25(OH)D concentration was observed after five months in the intervention groups receiving 10 µg and 20 µg doses of vitamin D_3 supplements, compared with placebo, among both Somali (East African) and Finnish (Caucasian) women. Figure 9 shows the effect of vitamin D_3 supplementation on S-25(OH)D among the participants (n=116) included in the analysis (repeated-measures ANCOVA, adjusted for baseline S-25(OH)D concentration). There were no significant differences found between the 10 µg and 20 µg intervention groups (p>0.05) in either of the two ethnic groups. Over the intervention period, the mean increase in the 10 µg D_3 supplement groups for Finnish and Somali women was +8.5 nmol/L (+14.1%) and +10.0 nmol/L (+19.2%), respectively, and that of the 20 µg D_3 supplement groups was +10.7 nmol/L (+17.7%) and +17.1 nmol/L (+32.7%), respectively. The mean decrease in placebo groups for Finnish and Somali women was -7.8 nmol/L (-13.0%) and -2.3 nmol/L (-4.4%), respectively. No significant differences emerged in response to vitamin D_3 supplementation

(p>0.05) between the two groups of women. Exclusion of the three Somali participants who were moved from the 20 µg group to the placebo group had no effect on the results. Adjustment for personal supplement use, dietary vitamin D intake, and BMI did not change the results.

No significant effect of vitamin D_3 supplementation was observed on S-PTH, S-Ca, or S-Pi in either Somali or Finnish women (p>0.05) (repeated-measures ANCOVA, adjusted for baseline S-PTH/S-Ca/S-Pi, data not shown).

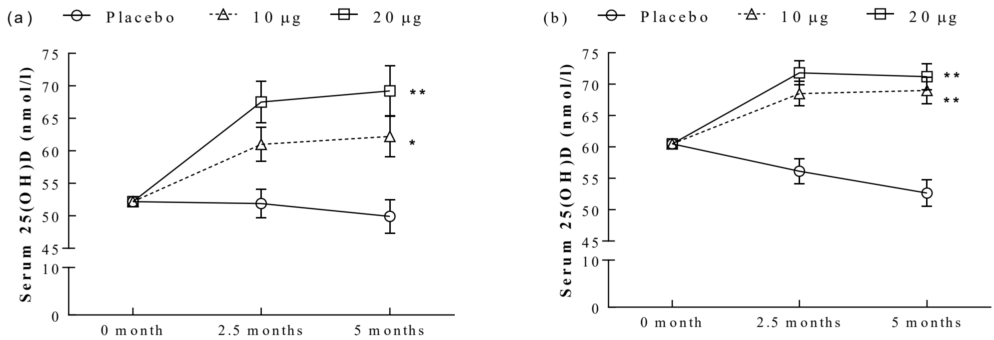

Figure 9. *Response of S-25(OH)D to vitamin D_3 supplementation in Somali (a) and Finnish (b) women (adjusted for baseline S-25(OH)D concentrations, repeated-measures ANCOVA).*

The time points are at 2.5-month intervals, representing mean values at each time point, error bars represent standard errors. Comparisons between intervention groups using contrasts: **p<0.001 and *p=0.003 for differences relative to placebo; p=0.105 for Somali and p=0.308 for Finnish women for differences between 10 µg and 20 µg groups in both ethnic groups.

6 DISCUSSION

This thesis (Studies I-III) is the first to examine food consumption and vitamin D status among immigrants of Russian, Somali, and Kurdish background in Finland. Ethnic differences between Somali and Finnish women in the effects of vitamin D_3 supplementation on vitamin D status were also investigated. Table 19 presents an overview of the main findings of each study. The results are subsequently discussed in detail.

Table 19. *An overview of the findings of Studies I-III.*

Study	What was known before	What this study adds
I		Ethnic differences in the consumption of healthy foods among Russian, Somali, and Kurdish immigrants; more frequent consumption of rye bread, fresh vegetables, and fruits and berries among Russians; low consumption of fresh vegetables and fruits and berries among Somalis; and lower fish consumption than recommended in all groups, especially among Kurds.
	Association between higher consumption frequencies of healthy foods and women, older age, and higher education.	Associations between healthy food consumption and socio-demographic factors, especially age, sex and education, in each ethnic group; healthy food consumption was more common among women, high-educated persons and older participants (except for fresh vegetables and fruits and berries among Somalis); household size and place of residence were somewhat associated with healthy food consumption.
II		Ethnic differences in the consumption of dietary sources of vitamin D among Russian, Somali, and Kurdish immigrants; more frequent use of vitamin D-fortified fat spread among Somalis than among Russians and Kurds; higher daily consumption frequency of vitamin D-fortified fluid dairy products among Russians and Kurds than among Somalis; and lower fish consumption frequency among Kurds than among Russians and Somalis.
	Insufficient vitamin D status is common among immigrants of Asian and African background compared with the host populations in Nordic countries.	Ethnic differences in vitamin D status among the immigrant groups compared with the general Finnish population; lower mean S-25(OH)D concentrations and higher prevalence of vitamin D deficiency (S-25(OH)D <30 nmol/L) among persons of Kurdish and Somali origin than among Russian participants or the Finnish general population.
	Age, high BMI, physical activity, daily smoking, alcohol intake, winter season, consumption of vitamin D-fortified dairy products and fatty fish,	Associations between low vitamin D status and some socio-demographic and health behaviour factors among the immigrants, namely; immigrant group, age, obesity, smoking, alcohol consumption, physical activity, winter season,

	and use of vitamin D supplements are associated with S-25(OH)D concentrations.	use of vitamin D supplements, and consumption of vitamin D-fortified fat spread, fluid dairy products, and fish.
III	Lower consumption of vitamin D-fortified milk among immigrant women than among Swedish women and low use of vitamin D supplements among immigrants from non-Western countries.	Differences in total vitamin D intake; higher intakes from food and supplements among Somali women than among Finnish women.
	Lower vitamin D status among Somali women than among Finnish and Swedish women in Finland and Sweden, respectively.	Differences in vitamin D status; lower baseline mean S-25(OH)D concentrations and higher prevalence of vitamin D deficiency and sufficiency among Somali women than among Finnish women.
	Increase in mean S-25(OH)D concentrations observed with 10 µg and 20 µg dosages of vitamin D_3 supplementation in RCTs, including ethnically diverse populations.	Increase in S-25(OH)D concentrations with 10 µg and 20 µg. vitamin D_3 daily supplementation in both Somali and Finnish women.
	Effect of vitamin D supplementation on S-25(OH)D is independent of race or ethnicity.	No ethnic differences in the response of S-25(OH)D to vitamin D_3 supplementation between Somali women and Finnish women.

6.1 Food consumption and associated socio-demographic factors among immigrants

Consumption of healthy foods, especially rye bread, fresh vegetables, and fruits and berries, was more common among Russian immigrants than among Kurdish and Somali immigrants. Consumption frequency of fresh vegetables and fruits and berries was low among Somalis. Fish as a healthy food and source of vitamin D was consumed less often than recommended in all immigrant groups, especially among Kurds. Somali immigrants used vitamin D-fortified fat spread more frequently than Russians and Kurds, while Russian and Kurdish individuals consumed vitamin D-fortified fluid dairy products more often daily than persons of Somali origin. Women consumed fresh vegetables (Kurds) and fruits and berries (Russians and Kurds) more often than men. Older participants more frequently ate rye bread (Somalis), vegetables (Russians), fruits and berries (Russians and Kurds), and fish (Somalis) than the youngest participants. Highly educated Somalis and Kurds consumed vegetables more often than the others. Russians with a larger household size frequently consumed rye bread, while Kurds living in the metropolitan area frequently consumed fish as indicators of healthy food consumption.

Healthy food consumption among immigrants

The selection of rye bread, vegetables, fruits and berries and fish as indicators of healthy food consumption was based on their positive impact on health (Nordic Council of Ministers 2014) and their significance within the Finnish food culture. Knowledge about the dietary habits of immigrants living in Finland is still limited (Prättälä *et al.* 2015). Having such nutritional information is important, especially in relation to the health profile of ethnic minority groups, which is often different from that of the host population (Stronks *et al.* 2013). Direct comparison could not be made between the immigrants in this study and the general Finnish population due to different dietary assessment methods. Nevertheless, the proportions of Russians and Somalis who ate rye bread and fish and of Russians and Kurds who consumed fruits and berries were not vastly different from that of the general Finnish population in the national dietary survey (FinDiet 2012) carried out during the same timeframe (Helldán *et al.* 2013). The proportion of the Finnish population that consumed vegetables was higher than that of the immigrant groups in this study (Helldán *et al.* 2013). The proportion of the population consuming selected healthy foods; rye bread (76%), vegetables (94%), fruits and berries (83%) and fish (45%), in FinDiet 2017 (Valsta *et al.* 2018) is quite similar to that of FinDiet 2012 (Helldán *et al.* 2013).

The higher frequencies in consumption of selected healthy foods among Russian immigrants depicted easy adaptation to the Finnish food habits, which can be partly explained by Russia and Finland being neighbouring countries with somewhat similar food cultures and similar traditional food products, e.g. rye bread (Paalanen *et al.* 2011). The higher consumption frequency of fruits and berries than vegetables among Kurds in this study is opposite to the findings observed by Kiadaliri (2013) in Iran, where consumption of vegetables was higher than that of fruits. This may be a reflection of the unavailability of commonly eaten vegetables in their home country and the greater varieties of fruits in Finland. A previous study in the United Kingdom also reported that 97% and 92% of the Somali population had low consumption of fruits and vegetables, respectively (McEwen *et al.* 2009). However, studies from the United States described frequent consumption of vegetables among Somalis; either as part of the main course or in salad (Decker 2006) and in cooked form together with meat or in stews (Davila 2001). Inclusion of fruits and vegetables in the diet is essential, and the views of Somali immigrants living in Finland warrant investigation.

The high rate of rye bread consumption in this study reveals some level of integration among the immigrants into the Finnish culture, as rye bread is considered a traditional Finnish food. The observed high consumption rate may be explained by frequent provision of rye bread in canteens. In addition, for Somali immigrants, rye bread consumption has likely been influenced by the variety of traditional breads, such as enjera or muufo, in their home country (Decker 2006). Adoption of rye bread as a part of the daily diet among immigrants will enhance good health if it is a replacement for the less nutritious white bread. Based on earlier reports, the low fish consumption among Somali and Kurdish immigrants in this study can be linked to cultural dietary preferences; meat is more valued in Somali meals (Decker 2006) and Kurdish households frequently eat meat and poultry as opposed to fish (Ahadi *et al.* 2014).

Association between healthy food consumption and socio-demographic factors among immigrants

Socio-demographic factors are important determinants of food consumption patterns among people, including immigrants (Barkoukis 2007, Sharma & Cruickshank 2011). Compared with the general Finnish population of the Health 2011 Survey (Männistö *et al.* 2012), the food consumption patterns among the immigrants in this study are similar to that of the Finnish population in terms of frequent healthy food consumption by older age groups and women. Studies have consistently reported higher consumption frequencies of healthy foods, especially fruits and vegetables, among women than among men (Prättälä *et al.* 2007, Marques-Vidal *et al.* 2018). Similar to the Finnish population in the past survey and the recent one (Männistö *et al.* 2012, Valsta *et al.* 2018), higher consumption frequencies of vegetables and fruits and berries were found among immigrant women than men. Red meat was consumed more frequently by Finnish men than women (Valsta *et al.* 2018). This study is in line with the previous observation regarding higher consumption of vegetables by Kurdish women than Kurdish men (Esteghamati *et al.* 2012) and more frequent consumption of fruits by Russian women than men (Paalanen 2013, Selivanova & Cramm 2014). Hence, based on the observed lower consumption frequency of healthy foods among men, this study supports the suggestion that men's approach towards nutrition knowledge is different from that of women and that there is an issue of pleasure-driven versus health-conscious food consumption patterns between men and women (Kiefer *et al.* 2005, Knudsen *et al.* 2014).

Positive associations between age and healthy dietary pattern are often observed in studies (Knudsen *et al.* 2014, Leone *et al.* 2017). Similarly, such associations have been reported with the frequency of fruit and vegetable consumption (Prättälä *et al.* 2007, Figueiredo 2008). The observed higher consumption frequency of fruits and berries among older Russian and Kurdish immigrants and the more frequent rye bread consumption among older Somalis were similar to findings in the Finnish population (Männistö *et al.* 2012). A possible explanation for the observed association between older age and consumption of healthy foods among Russians and Kurds may be increased age-related health concerns. Contrary to the findings of this study, older age was associated with lower consumption of fruit among Kurds in previous studies (Esteghamati *et al.* 2012, Kiadaliri 2013). In line with the cross-sectional studies carried out in Iran, Finland, Russia, and the Baltic countries (Prättälä *et al.* 2007, Paalanen *et al.* 2010, Sabzghabaee *et al.* 2010), high educational level was associated with increased consumption frequency of vegetables among Kurds and Somalis.

Regarding place of residence, similar findings of frequent weekly fish consumption were reported among Iranian families living in urban areas of Iran (Ahadi *et al.* 2014). Nevertheless, the observation of frequent vegetable consumption in urban households was contrary to the results among Kurds in this study (Ahadi *et al.* 2014). A high level of education and nutrition knowledge among urban households may partly influence Ahadi *et al.*'s findings. Despite similar access to healthy foods in all Finnish municipalities, the lower fruit and vegetable consumption found among Kurdish and Somali metropolitan residents may be associated with the easily accessible wide-ranging fast foods and unhealthy food choices in the metropolitan area (Thornton *et al.* 2009). Moreover, prices of some fruits and vegetables are higher, favouring the consumption of cheaper, less healthy foods (Popkin 2011). A positive association was observed between household size and rye bread consumption by Russians and Kurds and between household size and fresh vegetable consumption by Kurds. This finding may be related to the presence of a woman in households (Irz *et al.* 2014) and the increasing dietary diversity found in larger households (Thiele & Weiss 2003) compared with a one-person household with simple meals (Irz *et al.* 2014) that are probably less healthy.

Factors associated with adaptation to a new food culture were not examined in this thesis. Adaptation to the Finnish diet among Russian immigrants may be associated with a high level of acculturation (Neuhouser *et al.* 2004), which is quickly attained due to similar cultures in Finland and Russia. Notwithstanding the low consumption frequencies of fresh vegetables and fruits and berries among Somali immigrants in the present study, the observed higher frequencies among younger Somalis compared with their older counterparts reveals the possibility that age at the time of migration and generation status (Sturkenboom *et al.* 2016) may affect adaption to the Finnish food culture. Moreover, there is a tendency that other factors, such as acculturation (Neuhouser et al. 2004), making contacts with Finns (Nicolaou et al. 2006, Wandel et al. 2008), and having a good command of the Finnish language (Wandel et al. 2008), are easier for the younger generation of immigrants, facilitating convergence of dietary patterns with host food culture. Similarly, based on previous studies (Estaquio *et al.* 2009, Alkerwi *et al.* 2012, de Abreu *et al.* 2013), this thesis suggests that female sex, increasing age, and high level of education are associated with better adherence to nutrition recommendations among Russian, Somali, and Kurdish immigrants in Finland.

6.2 Differences in vitamin D intake and status between immigrants and the general populations

The prevalence of vitamin D insufficiency (S-25(OH)D ≥30 nmol/L but <50 nmol/L) was higher among the three immigrant groups (24% of Russians; 36% of Kurds; 52% of Somalis) than among Finns (6%). In the intervention study, lower baseline mean S-25(OH)D concentrations and higher prevalence of vitamin D deficiency and sufficiency were found among the screened Somali women compared with Finnish women who had no cases of vitamin D deficiency and insufficient status I only 9%. Vitamin D intakes from food and supplements were higher among Somali women than among Finnish women.

Differences in vitamin D intake

Vitamin D intake from food and/or supplements is essential to maintain sufficient vitamin status in northern countries such as Finland, especially during the winter months. The mean vitamin D intake from diet alone nearly reached the 10 µg daily recommended intake

(National Nutrition Council 2014) in both Somali and Finnish women. The vitamin D intake from food did not differ between supplement users and non-users in Somali and Finnish women. Nevertheless, the daily recommended intake was attained among the supplement users in both groups of women. The major contributing dietary source to daily vitamin D intake for both Somalis and Finns was fortified fluid milk products. Interestingly, higher consumption of vitamin D-fortified fluid milk products was observed among Somali women. Contrary to this finding, lower consumption of vitamin D-fortified milk was reported among immigrant women in Sweden compared with the Swedish reference group (Andersson *et al.* 2013). However, milk from camels, cattle, or goats is described as one of the staple foods (also beverage) in Somalia, and this may be the reason for the high milk consumption in this study (Burns 2004, FAO 2005, Decker 2006). Vitamin D intakes from fortified fat spreads and fish were similar in both Somali and Finnish women. According to the FinDiet 2017 report, the predominant dietary vitamin D source was vitamin D-fortified fat spreads, followed by of vitamin D-fortified milk products, and fish (Valsta *et al.* 2018). Low use of vitamin D supplements among immigrants, especially those from non-Western countries, has been observed (Andersson *et al.* 2013, Wändell 2013, Lips and de Jongh 2018). Similar results were previously seen among Somali immigrants in Finland and Norway (Madar *et al.* 2009, Islam *et al.* 2012). The use of vitamin D supplements was generally low for all study groups (immigrants and Finns). Nevertheless, significant differences were observed, in line with the earlier studies, between the immigrant groups (8-12%) and the general Finnish population (19%). In contrast to the previous studies (Madar *et al.* 2009, Islam *et al.* 2012), use of vitamin D supplement was higher among Somali immigrant women in the intervention study. However, the study is not directly comparable to the Maamu Study owing to its small sample size and different timeframe. In addition, the high supplement use among Somali women may be the result of feedback from the Maamu Study, in which some of them had been participants. Nevertheless, higher vitamin D intake may not necessarily be associated with higher S-25(OH)D concentration (Islam *et al.* 2012) as observed among the Somali women in this study.

Differences in vitamin D status

The findings of the present study support the results of an earlier small study on lower vitamin D status among immigrants in Finland, especially Somali women, compared with Finnish women (Islam *et al.* 2012). Cross-sectional studies comparing Somali immigrants with the native Swedish population have also reported lower S-25(OH)D concentrations among Somali immigrants (Fernell *et al.* 2010, Sääf *et al.* 2011, Kalliokoski *et al.* 2013, Bärebring *et al.* 2016). In other Nordic countries, insufficient vitamin D status has been noted in immigrants of Asian and African background compared with their host population (Meyer *et al.* 2004, Holvik *et al.* 2005, Madar *et al.* 2009, Andersson *et al.* 2013, Wändell 2013, Lips *et al.* 2019). With regard to similar mean S-25(OH)D concentrations among persons of Russian origin and the Finnish reference group, the findings of this study support those of a previous smaller non-representative study that evaluated S-25(OH)D concentrations among children and pregnant women in Finland and in the neighbouring Karelian Republic of Russia (Viskari *et al.* 2006). These results may be partly explained by the similar fair Caucasian skin colour, food consumption patterns, and outdoor activities among immigrants of Russian origin and the general Finnish population. The definition of Kurdish populations is not clear as they are incorporated in different countries such as Iran, Iraq, Turkey, and Syria. To the best of our knowledge, there are no other available studies on vitamin D status among immigrants of Kurdish and Russian origin, as specific groups, in other countries. The Kurdish immigrants and participants from Iran, Iraq, and Turkey in studies from Sweden were examined alongside other immigrant groups (Andersson *et al.* 2013, Granlund *et al.* 2016).

In this study, the proportions of persons with sufficient vitamin D status (S-25(OH)D ≥ 50 nmol/L) were lower among the Somalis (24%) and Kurds (15%) than among Russian immigrants (72%) and the Finnish general population (93%). Likewise, the proportion of sufficient vitamin D status was lower among Somali women (44%) than among Finnish women (91%) in the intervention study. Sufficient vitamin D status (S-25(OH)D >50 nmol/L) has been reported among the majority (77% and 91%) of Finnish adults in the national representative studies (Jääskeläinen *et al.* 2017, Raulio *et al.* 2017). For the immigrants, these findings raise concerns about associated adverse health outcomes, especially in relation to bone health, among Somali and Kurdish immigrants, as the majority of these individuals did could not reach the suggested threshold of ≥ 50 nmol/L considered to be sufficient for bone health (Ross *et al.* 2011). Hence, immigrants should not be considered as one group with similar health behaviours and challenges in terms of vitamin D status.

6.3 Determinants of low vitamin D status

Among the immigrants, Kurdish origin, obesity and daily smoking increased the odds of vitamin D deficiency, while increasing age, high physical activity, use of vitamin D supplements, and consumption of vitamin D-fortified fat spread and fluid dairy products were associated with reduced odds of deficiency. In addition, winter season, smoking, and excess alcohol consumption increased the odds of vitamin D insufficiency (<50 nmol/L), whereas being of Russian origin, increasing age, high physical activity, and frequent consumption of vitamin D-fortified fluid dairy products and fish were associated with lower odds of insufficiency.

The findings of this study demonstrated that frequent consumption of vitamin D-rich foods is important in preventing low vitamin status. The association of reduced odds of vitamin D insufficiency with consumption of vitamin D-fortified fluid dairy products and fish is in line with a previous study among immigrants in Sweden (Granlund *et al.* 2016) where fatty fish and fortified dairy products were identified as the important predictors of S-25(OH)D. As expected, consumption of vitamin D-fortified fat spread and fluid dairy products were also predictors of reduced risk of vitamin D deficiency. Despite the low proportion of vitamin D supplement users among the immigrants in this study, use of vitamin D supplements was associated with lower odds of vitamin D deficiency and this is consistent with other studies among immigrants (Madar *et al.* 2009, Granlund *et al.* 2016).

The effect of seasonal variation on S-25(OH)D is evident; as observed in this study, winter is often associated with increased risk of vitamin D deficiency and/or insufficiency (Thuesen *et al.* 2012, Yao *et al.* 2017). Association between obesity and vitamin D deficiency in this study is in line with previous studies regarding an inverse association between S-25(OH)D concentrations and BMI (Thuesen *et al.* 2012, Jääskeläinen *et al.* 2013, Mazahery & von Hurst 2015, Touvier *et al.* 2015, Yao *et al.* 2017). This association has been explained in terms of a possible reduction in the bioavailability of the synthesised vitamin D, which is deposited in the body fat compartment, due to the large fat mass in the body (Wortsman *et al.* 2000, Holick 2006).

Ageing is commonly associated with lower concentrations of S-25(OH)D (Mazahery & von Hurst 2015, Touvier *et al.* 2015) due to the reduction in the ability of the skin to synthesize vitamin D upon exposure to sunlight (Holick 2006). Unexpectedly in this study, increasing age was found to be associated with reduced odds of vitamin D deficiency and insufficiency; this is, however, consistent with the positive correlation between age and S-25(OH)D concentration among immigrants in Northern Sweden (Granlund *et al.* 2016).

Similar to earlier studies (Thuesen *et al.* 2012, Jääskeläinen *et al.* 2013, Kassi *et al.* 2015, Shinkov *et al.* 2015), daily smoking as an unhealthy lifestyle was a key determining factor for both vitamin D deficiency and insufficiency. Nonetheless, the reasons for these findings remain unknown. The observed association between excess alcohol consumption and vitamin D insufficiency is in contrast to the previous finding of positive associations between moderate alcohol intake and S-25(OH)D concentrations (Touvier *et al.* 2015). Despite no clear biological explanation, the association between physical activity and reduced odds of both vitamin D deficiency and insufficiency supports earlier results of a positive relationship between S-25(OH)D concentration and a physically active lifestyle

(Looker 2007, Thuesen *et al.* 2012, Yao *et al.* 2017). Nevertheless, such an association may be partly attributed to sun exposure during outdoor activities in summertime.

6.4 Effect of vitamin D supplementation on S-25(OH)D

An impact of vitamin D supplementation on S-25(OH)D was seen after a 5-month randomized controlled vitamin D dose-response trial among Somali and Finnish women. The findings showed that moderate vitamin D_3 supplementation of 10 µg and 20 µg daily was effective in increasing S-25(OH)D in Somali and Finnish women, while S-25(OH)D concentrations decreased significantly with placebo in both ethnic groups. No ethnic differences between the two ethnic groups were seen in the response of S-25(OH)D to vitamin D_3 supplementation.

Effect of vitamin D supplementation on S-25(OH)D has been extensively investigated in dose-response studies (Whiting *et al.* 2015), but few have been carried out in ethnically diverse populations (Aloia *et al.* 2008, Gallagher *et al.* 2013, Gallagher *et al.* 2014). The observed increase in mean S-25(OH)D concentrations with 10 µg and 20 µg dosages of vitamin D_3 supplementation in both Somali and Finnish women is consistent with previous RCTs among Pakistani immigrants (Andersen *et al.* 2008a) and Finnish women (Viljakainen *et al.* 2006). Effectiveness of 10 µg or 20 µg of vitamin D_3 supplementation has also been observed earlier in similar studies with participants with mean baseline S-25(OH)D concentrations above 50 nmol/L (Cashman *et al.* 2009, Nelson *et al.* 2009). A higher increase in S-25(OH)D than observed in this study, which means a stronger response to vitamin D_3 supplementation, was reported in previous studies (Viljakainen *et al.* 2006, Andersen *et al.* 2008a) due to lower baseline S-25(OH)D concentrations. Moreover, other RCTs conducted over one year or less found an increase in S-25(OH)D concentration above 50 nmol/L among subjects with vitamin D insufficiency (Viljakainen *et al.* 2006, Islam *et al.* 2010, Grønborg *et al.* 2015).

In studies by Gallagher *et al.* (2012, 2013), 10 µg dosage of vitamin D_3 increased S-25(OH)D concentrations by an average of 32.5 nmol/L, whereas 20 µg sufficiently increased S-25(OH)D above 50 nmol/L in 98% and 97.5% of Caucasian (baseline S-25(OH)D 39 nmol/L) and African American women (baseline S-25(OH)D 33 nmol/L), respectively. In line with the previous studies, our findings suggest that sufficient S-25(OH)D concentrations could be maintained with daily vitamin D supplementation at doses between 10 µg and 20 µg without exposure to UV radiation during winter. Hence, doses higher than 20 µg may not have substantial additional benefits among persons with sufficient vitamin D concentrations, as also proposed by Reid (2018). Despite the differences in vitamin D status between dark-skinned and fair-skinned populations, as observed also here, the response to vitamin D_3 supplementation in both Somali and Finnish women was similar. This is in accord with earlier findings that the effect of dose on S-25(OH)D is independent of race (Aloia *et al.* 2008, Gallagher *et al.* 2013). Since absorption and metabolism of vitamin D in dark-skinned and Caucasian individuals are also similar (Gallagher *et al.* 2013), this finding suggests that the common low vitamin D status among dark-skinned populations is probably associated with factors such as inadequate production of vitamin D in the skin, higher BMI, and genetics. Regarding vitamin D production in the skin, use of concealing clothes may be associated with lower S-25(OH)D concentrations among the Somali women of this study.

6.5 Methodology

6.5.1 Study population and design

The main strengths of this study include the use of data of rather large number of subjects from representative studies of immigrant (Russian, Somali, and Kurdish) and Finnish adults living in Finland (Castaneda *et al.* 2012, Lundqvist *et al.* 2016). The participation rates in the two population-based studies were relatively high: 70% for Russian (n=702), 51% for Somali (n=512), 63% for Kurdish (n=632) immigrants in the Maamu Study and 70% for the Finnish reference group (n=1582) in the Health 2011. The use of the two datasets from the immigrant population-based study (Maamu Study) and the Finnish national representative survey (Health 2011 Survey) allowed for comparison of vitamin D status between the immigrant groups and the general Finnish population. The design of the intervention study, a randomized, placebo-controlled trial, which offers the highest level of scientific evidence for causality (Ross *et al.* 2011), is a strength, as it enabled an objective evaluation of the effects of vitamin D_3 doses on S-25(OH)D. High quality, accuracy, and reliability of the datasets used in this study were ascertained by use of the participants' native language and preferred language (including translation when necessary) during the health examinations and interviews. With the population-based datasets, inverse probability weights were used to reduce bias due to non-response (Härkänen *et al.* 2014). Another strength of this study in terms of data reliability, especially in the intervention study, is the evaluation of compliance with vitamin D supplementation and the assessment of dietary vitamin D intakes at two different points of the study. The compliance rates with study vitamin D supplementation, blood sampling, and questionnaires (including FFQ) were high in both ethnic groups of women.

However, some issues emerged as limitations of this study. The cross-sectional setting of Studies I and II may not reveal true associations, as the design does not provide conclusive evidence for associations (Ross *et al.* 2011). Despite the representative samples of the studied populations in the Maamu Study (Russian, Somali, and Kurdish) and the Health 2011 (Finns), the non-participation somewhat reduced the representativeness and might have caused bias to the results, thus limiting external validity (Wihlborg *et al.* 2014). Although, weighting analyses were performed, correction for the effects of non-response may not have been fully achieved, especially among Somali participants in the Maamu Study, who had the lowest participation rate. According to Rechel *et al.* (2012), low response rates are a challenge identified in surveys of immigrants. Hence, these limitations must be considered when generalizing the findings outside Russian, Somali, and Kurdish populations in Finland. While the sample size allowed comparison between the Finnish reference group and the immigrants, in terms of background characteristics and vitamin D status, the unavailable data on S-25(OH)D concentration among younger Finnish adults (aged 18-29 years) restricts the comparison of findings in adults. The limitations in the external validity of this study also call for caution in applying the results for alcohol consumption, physical activity, and use of vitamin D supplements due to the high non-response rate, especially among Somali and Kurdish participants. It is also worth noting that generalizability of these results among other foreign-born populations in Finland is limited. The targeted sample size in the intervention study, based on power calculation, could not be fully reached due the seasonal timeframe (i.e. wintertime) of the study and challenges in recruiting immigrants. Hence, such limitations should be taken into consideration in future trials. The baseline mean S-25(OH)D concentrations (S-25(OH)D >50 nmol/L) in the intervention study were quite sufficient in both Somali and Finnish participants. Thus, the results may not be comparable with those of subjects with vitamin D deficiency. The non-restricted use of personal vitamin D supplement, especially among Somali women, during the intervention, may affect the interpretation of this finding. Lastly, the homogeneous composition of the intervention study in relation to sex (only women) limits the applicability of the findings to men in the population.

6.5.2 Dietary assessment

The dietary assessment was carried out differently in this study; dietary questions were asked during the interview in the Maamu Study, while a validated FFQ was included in the Marwo-D intervention. FFQ is the most suitable method in assessing long-term (6-12 months) habitual diet of individuals in large-scale epidemiologic studies. It enables the evaluation of participants' dietary intakes based on specific food items and relevant frequency options in combination with portion size (Willett 2013, Hörnell *et al.* 2017). The dietary questions employed in the Maamu Study were structured to measure food consumption frequencies and eating habits (Castaneda *et al.* 2012). Therefore, evaluation of food consumption, major dietary sources of vitamin D, and its actual intakes could not be done quantitatively. Furthermore, due to the structure of the dietary questions used in the Maamu Study, assessment of food consumption in terms of adherence to nutrition recommendations was not possible. The dietary questions were also limited in assessing diets of the immigrants because they were based on previous population surveys in Finland and on Finnish food culture. Hence, the complete dietary patterns of the immigrants in this study may not be revealed. However, the questions were indicators of integration and adaptation to the Finnish diet. Based on different dietary assessment methods, comparison between the immigrants and the Finnish reference group was not possible regarding consumption of healthy foods and vitamin D-rich foods. It is important to exercise caution in interpreting our results in relation to the time of data collection in the Maamu Study and the Health 2011 Survey (2010-2012); the situation may now be different.

The infrequent consumption of fresh vegetables, and fruits and berries among persons of Somali origin may be due to a misunderstanding of the questions, such as the one focusing on raw, fresh, and uncooked vegetables in the form of a salad. It has been reported that Somalis usually consume a variety of vegetables, which are cooked together with meat or in stews (Davila 2001). Hence, the lack of food frequency options capturing the dietary habits of Somalis might have affected their responses to the dietary question. The issue of misclassification or misidentification of foods not popular in their home country is another possible reason for the discrepancy. The use of different cut-offs for the consumption of vegetables and fruits and berries among Somalis affect comparisons with other groups.

Vitamin D intake in the intervention study was assessed based on an FFQ that had been validated against 3-day food records and biomarker S-25(OH)D among Finnish Caucasian women (n=67) (Itkonen *et al.* 2016a). The FFQ was found to provide a reasonable estimation of vitamin D intake among Finnish women (Itkonen *et al.* 2016a). The questionnaire retrospectively explores vitamin D intake over the past one month. The use of a booklet containing the pictures of vitamin D-fortified products for easy identification of consumed products by the participants during the interview enhances the quality of data collected through FFQ. Although the FFQ was piloted among a few Somali women, the use of an invalidated FFQ among the ethnic group might have resulted in incomplete evaluation of their vitamin D intake. The surprisingly higher vitamin D intakes among Somali women may partly be due to measurement error of the FFQ (such as over-reporting), which typically overestimates consumption more than other methods (Bärebring *et al.* 2018).

6.5.3 Serum 25(OH)D analyses

To facilitate measurement accuracy and comparison in S-25(OH)D concentrations regardless of time, laboratory, or assay method (Sempos *et al.* 2012), the S-25(OH)D concentrations in the Maamu Study and the Health 2011 Survey were standardized by VDSP using the gold standard LC-MS/MS. In addition, S-25(OH)D concentrations in the Marwo-D intervention study were analysed by LC-MS/MS, which was done with the same equipment used in standardising S-25(OH)D concentrations in both the Maamu Study and the Health, at the same laboratory: Cork Centre for Vitamin D and Nutrition Research at the University College Cork, Ireland. According to Sempos *et al.* (2012), VDSP ensures accurate measurement and more valid comparison of S-25(OH)D data across studies and time. This was achieved as the VDSP-standardized S-25(OH)D data allowed comparison of mean 25(OH)D concentrations and vitamin D status between the immigrant groups in the Maamu Study and the Finnish reference group in the Health 2011 Survey. Hence, the quality and reliability of this study's results are enhanced. In the intervention study, measurement accuracy was not an issue with the use of the LC-MS/MS method, which is considered a reference method (Wallace *et al.* 2010). In addition, as part of ODIN's project, S-25(OH)D concentrations are consistent with those of other work packages across Europe, which were analysed with the LC-MS/MS method in the same laboratory. Although adjusted in the analysis, the observed variation in the blood sampling period across the immigrant groups and the Finnish reference group may affect findings regarding the comparison of S-25(OH)D concentrations in the Maamu Study and the Health 2011.

7 CONCLUSIONS AND FUTURE PERSPECTIVES

In this thesis, diet and vitamin D status of immigrants of Russian, Somali, and Kurdish origin were examined. Moreover, the effects of vitamin D_3 supplementation on vitamin D status were investigated among Somali and Finnish women. The study revealed ethnic differences in the consumption of healthy foods among Russian, Somali, and Kurdish immigrants. There were ethnic differences in vitamin D status among the immigrant groups also compared with the general Finnish population. Nevertheless, there were no ethnic differences in the response of S-25(OH)D to supplementation between Somali and Finnish women. Based on the findings of this study, the following conclusions were made:

Study I: Consumption of healthy foods, especially rye bread, fresh vegetables, and fruits and berries, was more common among Russian immigrants than among Kurdish and Somali immigrants. There was low consumption of fresh vegetables and fruits and berries among Somali immigrants. The fish consumption was lower than recommended in all groups, especially among Kurdish immigrants. Female sex, older age, and higher education were associated with more frequent consumption of healthy foods.

Study II: Higher prevalence of vitamin D insufficiency (S-25(OH)D <50 nmol/L) and deficiency (S-25(OH)D <30 nmol/L) existed among immigrants, especially Kurds and Somalis, than among the Finnish general population. Differences emerged in the consumption of dietary sources of vitamin D; use of vitamin D-fortified fat spread was more common among Somalis than among Russians and Kurds; fish was consumed less by Kurds than by Russians and Somalis; and vitamin D-fortified dairy was more often consumed daily by Russians and Kurds than by Somalis. Daily smoking, alcohol consumption, and winter blood sampling were determinants of vitamin D insufficiency, while older age, physical activity, and consumption of fish and vitamin D-fortified dairy were associated with lower odds of insufficiency.

Study III: There was a high prevalence of vitamin D insufficiency (S-25(OH)D <50 nmol/L) among Somali women compared with Finnish women. Despite higher vitamin D intake among Somali women, they had lower baseline mean S-25(OH)D concentration than Finnish women. Moderate vitamin D_3 supplementation of 10 µg and 20 µg daily was effective in increasing S-25(OH)D concentrations in both Finnish and Somali women during the 5-month intervention, and no differences existed between the two ethnic groups in response of S-25(OH)D to vitamin D_3 supplementation.

In view of increasing immigration worldwide, the findings of this study offer up-to-date insights into immigrants' consumption of healthy foods, vitamin D intake, and vitamin D status. This study also provides novel information on the socio-demographic factors associated with healthy food consumption and the determinants of low vitamin D status among persons of Russian, Somali, and Kurdish origin living in Finland. In addition, this study adds knowledge about the effects of vitamin D_3 supplementation on S-25(OH)D in dark-skinned (Somali women) and Caucasian (Finnish women) populations.

Moreover, this thesis provides urgently needed information on immigrant groups, useful in the public health nutrition sector, especially in prevention of vitamin D insufficiency and its related diseases in Finland and internationally. The findings of this study serve as a resource for health policy makers in formulating recommendations that take into account different cultural backgrounds. Nevertheless, collection of follow-up data among the immigrant groups of the Maamu Study, such as was carried out among the general Finnish population (Health 2011 Survey), would be important for more up-to-date information and more detailed insight into food consumption and vitamin D status among immigrants in Finland.

In addition, comprehensive validated dietary assessment tools that take into account cultural food diversity within each immigrant group should be employed in such follow-up studies and other relevant future research among immigrants. Thus, actual dietary patterns, dietary intakes, main dietary vitamin D sources, and vitamin D supplements can be evaluated. Dietary research among immigrants has not received much attention in Finland. Hence, future studies covering different ethnic groups are needed, especially for deeper knowledge about the diet-related health profiles, including vitamin D status, among immigrants living in Finland. From another perspective, a wide range of immigrant populations should be included in the regular national dietary surveys in Finland, rather than merely studying these populations separately. Hence, ethnic background/country of origin would be examined as one of the socio-demographic characteristics and not as the main characteristic of the participants. This is important especially when studying the second and third generations of immigrants who should be considered Finns, not immigrants.

With regard to low consumption of fruits, berries, and fresh vegetables among Somali immigrants, studies are needed to further investigate the situation in Finland, and if the findings of this study are sustained, an intervention may be warranted. Efforts to promote healthy food consumption, including vitamin D-rich foods for better vitamin D status, in adherence to the nutrition recommendations among all immigrant groups are also essential. Since causality could not be concluded with cross-sectional studies, follow-up and intervention studies are required to shed light on socio-demographic factors associated with healthy food consumption and the determinants of low vitamin D status among immigrants. Moreover, large sample studies, preferably RCTs, aiming to investigate vitamin D status in terms of the effect of supplementation, associated factors and both skeletal and non-skeletal health outcomes are required among immigrants, especially the dark-skinned populations who are at the greatest risk of vitamin D insufficiency.

In terms of vitamin D status, immigrant groups cannot be studied as a homogeneous group. Hence, consideration for factors such as skin colour, country, and culture of origin is desirable in future research since the most important determinants of vitamin D status (such as wearing of concealing clothes, smoking habits, dietary habits, and physical activity) are partly associated with learned cultural behaviours. With increasing evidence of poor vitamin D status among the non-Western immigrants living in northern countries such as Finland, actions to prevent insufficient vitamin D status and improve the treatment of public health problems related to insufficiency are important. Immigrants need to be advised on making healthy dietary choices from both their cultural foods and foods available in their host countries. These efforts will help to eliminate the existing health inequalities between immigrants and host populations. In addition, it is important to investigate vitamin D status among immigrant children and adolescents, which is presently unknown in Finland.

Finally, this thesis clearly shows that food consumption and the degree of risk of vitamin D insufficiency are not similar among all immigrant groups and that the differences are related to the country of origin. Hence, it is worth noting that immigrants should not be considered as one group with similar health behaviours and challenges, especially in terms of vitamin D status, when formulating public health policies.

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APPENDIX

APPENDIX. The Marwo-D intervention study food frequency questionnaire (Study III).

How often have you consumed the following foods during the last month?	Portions/ Day	Portions/ Week	Portions/ Month	More rarely/ Not at all
FLUID DAIRY PRODUCTS				
Milk or sour milk (1 glass, 1.7 dl)				
Valio Eila lactose-free milk or sour milk (1 glass, 1.7 dl)				
Valio Plus milk or sour milk (1 glass, 1.7 dl)				
Organic milk, sour milk, or raw milk (1 glass, 1.7 dl)				
Soy, oat, rice, hazelnut, or almond drink (fortified with vitamin D) (1 glass, 1.7 dl)				
Organic soy, oat, rice, hazelnut, or almond drink (1 glass, 1.7 dl)				
Milkchocolate or milkshake (1 glass, 1.7 dl)				
Latte or cappuccino (1 cup, 1.7 dl)				
Coffee or tea with milk (2 tbsp, 30 ml)				
Porridge, cereal, or muesli with milk or plant-based drink (1 dl)				
YOGHURT, CURDLED MILK, AND QUARK				
Yoghurt (1 pot, 175 g)				
Soy yoghurt (fortified with vitamin D) (1 pot, 175 g)				
Quark (1 pot, 200 g)				
Curdled milk (1 pot, 200 g)				
Organic yoghurt, quark, or curdled milk (1 pot, 175 g)				
Pudding or soy pudding (fortified with vitamin D) (1 pot, 120 g)				
Power drink yoghurt/smoothie (special trademark: Valio Gefilus) (1 bottle, 1 dl)				
Recovery or protein drink (e.g. Gainomax, Teho, Profeel) (1 can, 2.5 dl)				
CHEESE AND BREAD				
Valio Polar cheese (1 slice)				
Vitamin D-fortified bread (Ruis Aurinko D+) (1 slice, 30 g)				
Other bread slices or rolls (including crispbread / rye crisps) **(**1 slice, 30 g)				

Appendix continues.

How often have you consumed the following foods during the last month?	Portions/ Day	Portions/ Week	Portions/ Month	More rarely/ Not at all
DAIRY-BASED DISHES				
Milk-based soups (e.g. fish, summer=veggies and potatoes) (1 portion=1 plate, 300 g) Specify?______________________________				
Porridge or gruel, cooked with milk (1 plate, 230 g)				
Porridge or gruel, cooked with water (1 plate)				
Thin pancakes (made with milk) (4 small or 1 big, 70 g)				
Pancake made with milk (1 slice, 65 g)				
MAIN COURSES				
Macaroni casserole or lasagne, also meat-free (1 plate, 300 g)				
Liver casserole (1 plate, 300 g)				
Other liver dish (e.g. sauce/2 steaks, 150 g)				
Egg (boiled, fried, omelette, 1 piece)				
MUSHROOMS				
Chanterelle or funnel chanterelle (cooked, 1 dl)				
Boletus, russula, or milk caps (cooked, 1 dl)				
FISHES				
Raw pickled or cold-smoked rainbow trout or salmon (15 g)				
Rainbow trout (110 g)				
Salmon (110 g) or salmon in soup (55 g)				
Pikeperch (160 g)				
Whitefish (160 g)				
Perch (160 g)				
Baltic herring (1 piece, 30 g)				
Tuna (1 can, 150 g)				
Pollock (160 g)				
Fish ball or steak (3 pieces or 1 piece, respectively, 120 g)				
Fish stick (1 piece, 25 g)				
Herring (1 slice, 5 g)				
Other fishes, what?_________________________________				
FORTIFIED JUICES AND MINERAL WATERS				
Special juice/juice with whey (fortified with vitamin D) (e.g. Gefilus, Marli Vital) (1 glass, 1.7 dl)				
Mineral waters (fortified with vitamin D) (e.g. Vitamin water multi-v, 1 bottle, 5 dl)				

Appendix continues.

FAT

What kind of fat spread do you usually use on bread?
1 none
2 butter
3 butter-vegetable oil mixture, explain what?______________________
4 margarine or light fat spread, explain what?_________________
5 soya-based fat spread, explain what?___________________
6 other, explain what?___________________
How much fat spread do you use on bread?
1 very thin layer (3 g, one can see the bread)
2 lightly (5 g, a thin layer on bread)
3 strongly (10 g, a thick layer on bread)

What kind of spread do you usually use in porridge?
1 none
2 butter
3 butter-vegetable oil mixture, explain what?______________________
4 margarine or light fat spread, explain what?_________________
5 soya-based fat spread, explain what?____________________
6 other, explain what? ___________________

What kind of fat do you usually use at home (e.g. for cooking)?
1 none
2 butter
3 butter-vegetable oil mixture, explain what?______________________
4 margarine or light fat spread, explain what?_________________
5 soya-based fat spread, explain what?____________________
6 fluid margarine, explain what?___________________
7 vegetable oil, explain what?__________________________
8 other, explain what? ___________________

How often do you cook at home a dish for which you use fat?
______ times a day
______ times a week
______ times a month

What kind of fat do you <u>usually</u> use in baking?

1 none
2 butter
3 butter-vegetable oil mixture, explain what?____________________
4 margarine or light fat spread, explain what?________________
5 soya-based fat spread, explain what?___________________
6 fluid margarine, explain what?_________________
7 vegetable oil, explain what?_________________________
8 other, explain what? _________________

What kind of <u>homemade</u> pastries/confectionary products baked with margarine have you eaten <u>during the last month</u>? How much and how often? (*e.g. 3 cinnamon rolls per month or one brownie per week***).**

What?_________________Quantity:_____pcs/day/week/month. Baking fat:___________

What?_________________Quantity:_____pcs/day/week/month. Baking fat:___________

What?________________Quantity:_____pcs/day/week/month. Baking fat:___________

What?_________________Quantity:_____pcs/day/week/month. Baking fat:___________

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